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The Gain in Nitrogen from Growth of Legumes on Acid Soils

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The Gain in Nitrogen from the Growth of Legumes on Acid Soils*

There are millions of acres of land covering two-thirds of Wisconsin which are not only acid but also deficient in nitrogen and organic matter.

Frequently soil of this character will not grow profitable crops unless the deficiencies are met in some way. Soil acidity can easily be remedied by the use of lime.

Leguminous plants such as alfalfa, clover, or soy beans are used to maintain a supply of nitrogen in the soil. In a favorable environment, legumes through the work of certain bacteria will take nitrogen from the air and "fix" or place it in the soil where it can be used as plant food. In almost any system of farming it is necessary to give a leguminous crop an important place in the crop rotation.

Three conditions which affect the nitrogen-fixing power of the legumes are: the presence of the proper bacteria in the soil, the presence of large amounts of soluble nitrogen, and the acidity of the soil.

The presence of the proper bacteria in the soil can be secured by inoculation with soil or by means of artificial cultures. The second factor does not play an important part under field conditions because large amounts of soluble nitrogen rarely occur. To the farmer the third factor is a most important one, much data having been collected which shows that an acid reaction of the soil is injurious to crop growth.

It is a common experience that some legumes do not thrive very well in acid soils and as a result may not be very efficient in restoring nitrogen to the soil. Fortunately, there are certain cultivated legumes which do well in acid soils. Although these plants often develop normally, showing an abundant growth and a large root system with numerous

*The authors are indebted to Professors E. G. Hastings and A. R. Whitson, for many helpful suggestions during the progress of the study, and the preparation of the manuscript.

nodules, information regarding their nitrogen-fixing powers is somewhat meager.

Since medium red clover, alfalfa, and soy beans are better forage crops than most of the legumes which will grow on

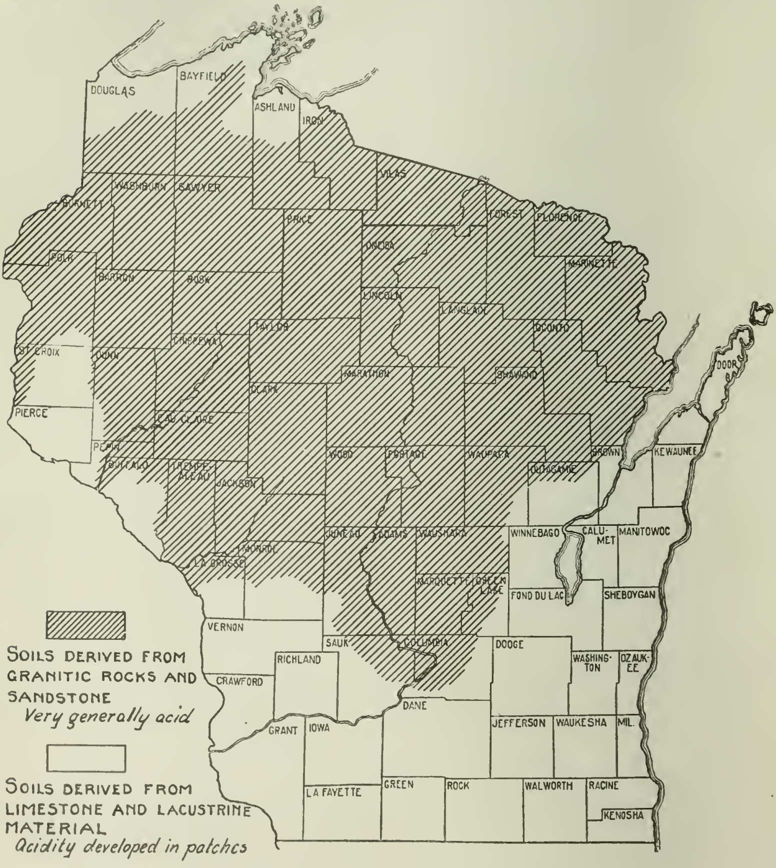

FIG. 1.—EXTENT OF ACID SOILS IN WISCONSIN

The silt and clay loams of the North Central area are very generally acid. The sandy soils are universally acid. Acidity has developed in patches in the soils on limestone.

acid soils, it is desirable to correct the acidity of the soil so that they can be grown. When the cost of lime, which is used to correct the acidity of the soil, is too great, legumes which will grow on acid soils should be used.

Since many of the legumes do not grow under very acid conditions, the question of partial neutralization of the soil

acidity becomes important. Again, where a high degree of acidity exists over a large portion of the farmer's land, the amount of land which can be used for the growing of alfalfa in rotation presents another problem.

A constantly increasing demand for greater crop production makes it important to study methods of increasing the growth of legumes. The application of limestone to neutralize soil acidity offers a possible solution. Accordingly experiments were planned, which had as their chief purpose a study of the growth and nitrogen-fixing power of acid-tolerant and acid-sensitive legumes, grown on acid soil. The three most promising leguminous crops for Wisconsin, common red clover, alfalfa, and soy beans, were selected for this investigation. It was arranged to measure the value of these crops for two widely different types of acid soil. This study included the influence on plant growth of certain factors other than soil type, i. e., inoculation and limestone. The following points were considered: First, the gain in nitrogen and plant growth from inoculation; second, the relative benefit derived from large and small applications of limestone, both inoculated and uninoculated; third, the nitrogen balance in an acid soil before and after growing a leguminous crop, provided the aerial crop was removed and the roots left in the soil.

Although the experiments have been made both in the glass house and in the field, the greater portion of the data reported herewith was obtained from pot experiments. Since the results of field tests for one season agree very closely with those obtained in the glass house, it was deemed best to publish the data of these experiments. This is not a completed study but a progress report of the results up to the present time.

HISTORICAL REVIEW

A demonstration of the ability of inoculated legumes to add nitrogen to the soil has been shown by the results of various investigators. Since the literature on this subject is extensive, it is proposed at this time to give only a brief review of certain investigations.

Atwater and Woods (3) of the Connecticut Station were among the first in America to show the beneficial effect of

inoculation on growth and nitrogen content of alfalfa and peas. They found, when alfalfa was grown on sand supplied with nutrient solutions, a gain in nitrogen resulted. The increase was proportional to the number of nodules on the roots. The results obtained with alfalfa were substantiated with peas grown under similar cultural conditions.

Numerous experiments carried on at the Rothamsted Experiment Station (21) gave evidence that legumes had the ability, when properly inoculated, to increase the nitrogen content of the soil. A field where six crops of wheat had been grown previously was chosen and divided into two subfields. On one field barley was seeded, on the other clover. After the crops were harvested. the soil from each field was analyzed for total nitrogen. The clover field to a depth of nine inches contained 0.156 per cent of nitrogen, the soil from the barley field contained 0.142 per cent. Many similar experiments are on record.

The beneficial effect of inoculation was shown by Duggar (4) who found that Canada field peas, crimson clover, lupines, vetches, and other legumes were benefited by the treatment. In some cases, an increase in crop growth of more than 300 per cent was secured. This investigator (5) carried on numerous field tests and found that vetch was greatly benefited by inoculation. He found also that less than one-fifth of the total nitrogen of the plant is in the roots and short stubble.

In a report of pot and field experiments, Hopkins (9) found a fixation of over 35 pounds of atmospheric nitrogen per acre due to inoculation. The effect of lime and other fertilizers was studied both under greenhouse and under field conditions. Beneficial results from the use of lime were reported in all cases.

Nobbe and Richter (15) found that inoculation increased the percentage and total nitrogen in tops of *Vicia Villosa*, as well as the dry weight of the crop. They noted that inoculated plants contained 4.29 per cent of nitrogen and uninoculated plants only 1.85 per cent. Studies by these same investigators on the effect of nitrates on the percentage of nitrogen fixed from the atmosphere gave evidence that where soluble nitrogen is present in considerable quantity, the percentage fixed from air may be greatly reduced.

According to Smith and Robison (19) inoculation greatly increases the percentage of nitrogen in the parts above ground of soy beans and cowpeas. Inoculated beans, for example, not only gave more nitrogen in stems and leaves, but also a decided gain in percentage of nitrogen in the seeds. In many cases, inoculation failed to show any marked increase in yield, but the harvest was much richer in nitrogen. This work was extended by Shutt (17) who found that inoculation increased the protein content of alfalfa hay. He reports that clover grown on a sandy loam soil for six consecutive years increased the nitrogen content of that soil 375 pounds per acre.

According to Alway (1) inoculation nearly doubles the percentage of nitrogen in the crop. Aside from the increase in the percentage of nitrogen, he found that the roots and stems are from three to fifty times as heavy as those from the uninoculated plants.

Greenhouse experiments carried on by Hartwell and Pember (8) at the Rhode Island Station resulted in a fixation of one ton of nitrogen per acre from legumes grown successively for a period of five years.

Arny and Thatcher (2) of the Minnesota Station have submitted data concerning the effect of inoculation on alfalfa. They report not only an increase in yield from inoculation, but also a decided increase in percentage of nitrogen. It appears that the benefit derived from inoculation was much greater in the tops than in the roots.

According to Morse (14) of the Massachusetts Experiment Station, liming caused an increase in the size of clover plants and also an increase in percentage of nitrogen. Analysis of plant tissue failed to show any effect of the lime on the percentage of ash, iron oxide, and calcium oxide.

The value of legumes as a source of nitrogen has been reported by Lipman and Blair (13). In a four-year rotation on various soils they found that the growth of legumes as green manures results in an average gain per acre of more than 54 pounds of nitrogen annually.

EXPERIMENTAL METHODS

This paper includes a report of results obtained from pot experiments with alfalfa, red clover, and soy beans on acid

soils. Similar experiments under field conditions are now in progress.

SOIL

Two types of acid soil were used for this work—namely, Colby silt loam and Plainfield sand. The Colby silt loam was collected from the sub-station at Marshfield; the Plainfield sand from the experiment field at Sparta. These soils were shipped to the laboratory where they were passed through a four-millimeter sieve and mixed thoroughly. Samples were drawn for moisture content, active acidity, and total nitrogen.

The following table gives the average chemical composition of several samples of these soils:

Soil	P.	N.	K.	Organic matter
Colby silt loam	.072	.198	1.51	3.91
Plainfield Sparta sand	.032	.09	.93	1.67

METHODS

In order to determine the amount of calcium carbonate necessary to neutralize the acidity of the soils, the Veitch and Truog methods were used.

The total nitrogen content of the tissue was determined by the Kjeldahl method, digesting for four hours with sulphuric acid, potassium sulphate and copper sulphate. The figures of the following tables represent the average of three analyses.

After all crops were harvested and the roots of the alfalfa plants removed, the soil was mixed thoroughly. One-half kilogram samples were drawn, allowed to dry and prepared for analysis. In the presence of appreciable amounts of nitrate nitrogen, the modified method for total nitrogen to include nitrates was followed. For each soil four parallel analyses were made.

Pounds per acre.—It was assumed that one gram of tissue or of nitrogen per jar of 10½ inches in diameter corresponds to one pound per square rod or to 160 pounds per acre (9).

In the 1914 experiments, the lime requirement was determined by the Veitch method. In all subsequent work, it was determined by the Truog method. A series of earthen-

ware jars, each $10\frac{1}{2}$ inches in diameter and 12 inches deep, were filled with a definite amount of the various soils. The jars were kept in a special greenhouse in order to avoid contamination. A general plan of all of the experiments is given below.

PLAN OF EXPERIMENTS

Pot No.	Treatment	
1	None	Uninoculated
2	None	Uninoculated
3	None	Inoculated
4	None	Inoculated
5	$CaCO_3$ one-half*	Uninoculated
6	$CaCO_3$ one-half	Uninoculated
7	$CaCO_3$ one-half	Inoculated
8	$CaCO_3$ one-half	Inoculated
9	$CaCO_3$ full	Uninoculated
10	$CaCO_3$ full	Uninoculated
11	$CaCO_3$ full	Inoculated
12	$CaCO_3$ full	Inoculated

*By "one-half" is meant the amount of lime carbonate necessary to neutralize one-half of the acidity.

Before planting, all seeds were washed in mercuric chloride and rinsed in sterile water. The seeds in one-half of the pots were inoculated with a pure culture of alfalfa bacteria, clover bacteria or soy bean bacteria. Wherever seedlings were used instead of seed, they were first grown in sand and then transferred to proper jars.

The moisture content was maintained at 60 per cent saturation for the Colby silt loam and at 50 per cent saturation for the Plainfield sand.

Results of Pot Experiments for 1914

The first experiment was started late in the spring of 1914. At that time only one soil type, Colby silt loam, was available. After determining the soil acidity, carbonate of lime was added as follows: jars 5 to 8 inclusive received .0808 gram per 100 grams of soil, jars 9 to 12 inclusive received .1617 gram per 100 grams of soil. The first amount is sufficient to neutralize one-half, and the last amount, all of the acidity indicated by the Veitch method. The lime was added in the form of pure calcium carbonate and intimately mixed with the soil.

THE EFFECT OF TREATMENT ON THE YIELD OF ALFALFA AND SOY BEANS

May 29, 1914, the jars were planted to alfalfa. The seed germinated well, giving a uniform stand. After two weeks the seedlings were thinned to 35 per jar. For several weeks after planting, the seedlings in all jars appeared much alike. After about six weeks, the uninoculated unlimed plants began to turn yellow and remained this color during the entire growing period.

TABLE I.—THE INFLUENCE OF INOCULATION WITH AND WITHOUT LIME ON GROWTH AND NITROGEN CONTENT OF ALFALFA ON COLBY SILT LOAM

Pot No.	Dry weight of different crops				Nitrogen in different crops							
	Tops 1	Tops 2	Tops 3	Roots	Tops 1	Tops 2	Tops 3	Roots	Tops 1	Tops 2	Tops 3	Roots
	Gms.	Gms.	Gms.	Gms.	Mgm.	Mgm.	Mgm.	Mgm.	P. Ct.	P. Ct.	P. Ct.	P. Ct.
1	14.3	7.23	4.66	20.34	531.2	294.9	225.4	618.0	3.71	4.07	4.83	3.04
2	13.23	5.29	3.94	18.20	533.1	220.6	175.5	539.3	4.02	4.17	4.45	2.96
Av.	13.76	6.26	4.30	19.27	532.1	257.7	200.4	578.6	3.86	4.12	4.64	3.00
3	15.54	5.84	4.94	18.36	613.6	239.3	233.7	513.2	3.94	4.09	4.73	2.80
4	15.74	6.43	4.03	15.16	680.4	268.5	195.4	496.4	4.32	4.17	4.84	3.20
Av.	15.64	6.13	4.48	16.76	647.0	253.9	214.5	504.8	4.13	4.13	4.78	3.00
5	14.42	5.62	4.86	18.85	592.6	246.2	231.5	546.3	4.11	4.38	4.76	2.90
6	15.29	5.64	4.59	20.87	648.2	260.8	197.2	609.6	4.23	4.62	4.29	2.92
Av.	14.85	5.6	4.72	19.86	620.4	253.5	214.3	577.9	4.17	4.50	4.52	2.91
7	16.74	7.34	5.15	24.88	712.2	327.7	249.1	737.8	4.25	4.46	4.83	2.97
8	16.79	6.59	4.71	24.53	712.4	285.2	222.6	694.0	4.24	4.32	4.72	2.90
Av.	16.76	6.96	4.93	24.70	712.3	306.4	235.8	715.9	4.25	4.39	4.77	2.93
9	14.08	5.86	4.62	24.00	549.2	246.5	204.3	662.3	3.90	4.20	4.42	2.76
10	15.89	7.16	5.18	22.79	622.4	306.2	228.9	686.3	3.91	4.27	4.41	3.01
Av.	14.98	6.51	4.90	23.39	585.8	276.3	216.6	674.3	3.90	4.23	4.41	2.88
11	18.21	8.20	5.00	19.71	768.8	357.5	235.2	587.8	4.22	4.35	4.70	2.98
12	18.48	8.97	4.52	18.24	761.7	385.0	218.7	560.3	4.12	4.29	4.83	3.07
Av.	18.34	8.58	4.76	18.97	765.2	371.2	226.9	574.0	4.17	4.32	4.76	3.02

Five crops in all were taken from the soil in this series, three of alfalfa and two of soy beans. After the third crop was harvested and the roots carefully removed, the jars were planted to soy beans.

The first crop of alfalfa was harvested on October 6, 1914. The second crop was harvested on November 19, and the third on January 2, 1915. The crops were air dried and kept for analysis.

YIELD OF ALFALFA

Table I gives the dry weights, the total nitrogen, and percentage of nitrogen in the different crops. From the data presented in the table, it will be seen that the maximum yield was obtained with the first crop. Because of weather conditions, very little sunlight, etc., the later cuttings of alfalfa were much lighter. The data show, moreover, that the benefit derived from inoculation alone was most marked in the first crop. The dry weight* of the first cutting, uninoculated jars 1 and 2, was 13.7 grams as compared with the inoculated jars 3 and 4, 15.6 grams, an increase of 1.9 grams or 13.8 per cent. The second and third crops failed to show any noticeable difference in weight. The uninoculated plus half lime,** jars 5 and 6, produced slightly more growth in the first and third crops than did the corresponding control jars 1 and 2, while the inoculated jars 7 and 8, plus half lime, produced larger yields in every case than the controls. The increase in this series amounted to 3 grams or 21.6 per cent.

Where full lime was applied, the inoculated jars 11 and 12 gave, in the first cutting, a yield of 4.58 grams more than the control, or a gain of 33.2 per cent, and in the second cutting a gain of 37.0 per cent. The average weight of dry matter, duplicate pots, for the three crops was as follows:

Controls uninoculated	24.33 grams
Controls inoculated	26.26 grams
One-half lime uninoculated	25.21 grams
One-half lime inoculated	28.61 grams
Full lime uninoculated	26.40 grams
Full lime inoculated	31.69 grams

The results as a whole show that inoculation without other treatment is beneficial to the growth of alfalfa in acid soils, especially to the first crop. Likewise, lime enhances crop production. Lime alone, when applied in small amounts, gave a slight increase, but not nearly so much as inoculation alone. One-half lime and inoculation combined gave a greater yield than either alone. Where larger amounts of lime were applied, a correspondingly larger yield was obtained. Jars 11 and 12 inoculated with full lime produced

*Whenever crop yields or percentages of nitrogen or total nitrogen are compared, the average of duplicate jars is taken as a basis for comparison.
**Wherever the term "lime" is used, pure calcium carbonate is meant.

the maximum gain in growth. For the maximum production of alfalfa hay on Colby silt loam soil, lime and inoculation are essential. Figure 2 shows, at a glance, the differences in yield of the various crops.

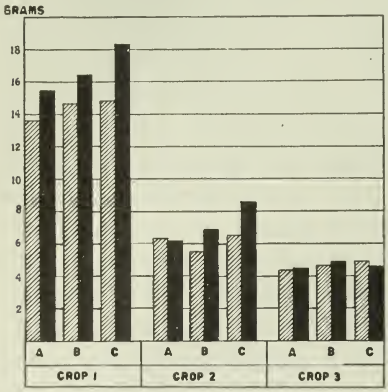

FIG. 2.—GROWTH OF ALFALFA ON COLBY SILT LOAM.

a. Control; b. half lime; c. full lime. The checked columns denote uninoculated and the dark columns inoculated.

January 2 the alfalfa was cut for the last time, the roots carefully removed, and nodule formation recorded. The root tissue including the nodules was saved for analysis. In removing roots from the soil, a considerable portion of the finer roots was unavoidably left in the soil. For this reason it was difficult to determine the true benefit from the use of lime and inoculation. In all cases, except jars 1 and 2, the roots showed a profuse development. A few nodules were present on all the uninoculated roots. All of the inoculated roots were thoroughly infected with numerous nodules.

YIELD OF SOY BEANS

February 15, 1915, the jars were replanted to Ito San soy beans. The bacteria-free seeds were germinated in sterilized sand. Only 10 plants were allowed to mature in each jar. The plan followed was the same as in the previous experiment. Because of the cold and cloudy weather, growth was very poor. As late as April 1 the plants were partially yellow and badly infected with red spider. The crop was harvested April 26, the tops removed, weighed, and kept for analysis. A record of nodule production was made. Jars 1, 5, 6, and 9 were free of all nodules; 2 and 10 contained one nodule each; 3, 7, 8, 11, and 12 contained numerous nodules and jar 4 a few nodules.

The experiment was repeated, using Wisconsin Black soy beans, an early maturing variety. The first of May, 25 seeds free of bacteria were planted in each pot. The seeds

in inoculated jars were treated with a pure culture of soy bean organisms. It was found that Wisconsin Black soy beans grew better and produced larger yields than the Ito San soy beans. Here again, only 10 plants were allowed to mature in each jar. After the first month the uninoculated plants turned yellow and the leaves began to drop. On July 12 this crop was harvested, weighed, and kept for analysis. After noting nodule development, the roots were incorporated with the soil. Jars 1 and 10 were slightly inoculated; all other uninoculated jars were free of nodules. All inoculated jars showed numerous nodules.

TABLE II.—THE INFLUENCE OF INOCULATION WITH AND WITHOUT LIME ON GROWTH AND NITROGEN CONTENT OF SOY BEANS ON COLBY SILT LOAM

Pot No.	Dry weight of different crops		Nitrogen in different crops			
	Tops 1	Tops 2	Tops 1	Tops 2	Tops 1	Tops 2
	Gms.	Gms.	Mgm.	Mgm.	P. Ct.	P. Ct.
1	16.79	14.10	572.9	427.5	3.41	3.03
2	17.96	14.50	569.7	483.5	3.17	3.32
Av.	17.37	14.30	571.3	455.5	3.29	3.17
3	16.64	17.64	648.1	612.2	3.89	3.47
4	13.62	18.43	546.7	670.3	4.01	3.65
Av.	15.13	18.03	597.4	641.2	3.95	3.56
5	17.46	14.04	523.8	376.0	3.00	2.68
6	16.86	17.54	546.4	349.6	3.24	2.00
Av.	17.16	15.79	535.1	362.8	3.12	2.34
7	16.19	19.03	602.8	634.8	3.72	3.34
8	17.06	17.21	665.3	570.2	3.90	3.31
Av.	16.62	18.12	634.0	602.5	3.81	3.32
9	17.46	14.60	543.0	330.8	3.11	2.26
10	20.86	15.03	645.6	390.0	3.09	2.60
Av.	19.16	14.81	594.3	360.4	3.10	2.43
11	20.86	19.48	812.5	683.3	3.89	3.51
12	19.47	17.68	755.2	604.0	3.88	3.42
Av.	20.16	18.58	783.8	643.6	3.88	3.46

In Table II are recorded the complete data for this experiment.

The first crop did not respond favorably to treatment, except in jars 9, 10, 11, and 12, where a slight increase was noted.

The second crop responded favorably to inoculation, but failed to produce an appreciable increased yield in the presence of lime. This does not agree with results from the Alabama Station (6), where lime caused an increase in yield of

soy beans of 49 per cent. A possible explanation for this may be found in the difference in soil type. The precentage increase due to inoculation was 26.0, to inoculation plus full lime, 29.9, and lime alone, 3.9. In order to bring out more clearly the effect of treatment on the growth of soy beans, the results of the preceding table have been arranged in the form of columns as shown in Figure 3.

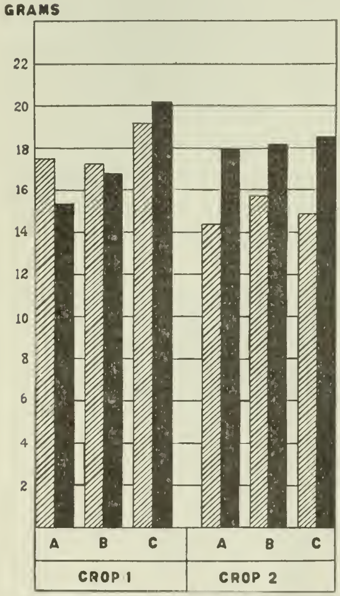

FIG. 3.—GROWTH OF SOY BEANS ON COLBY SILT LOAM

a. Control; b. half lime; c. full lime. The checked columns denote uninoculated and the dark columns inoculated.

THE EFFECT OF TREATMENT ON THE NITROGEN CONTENT OF ALFALFA AND SOY BEANS

The influence of inoculation alone and with lime on the total quantity of nitrogen and percentage of nitrogen will be discussed under this head.

NITROGEN CONTENT OF ALFALFA

From the data of Table I, it will be seen that the percentage of nitrogen varies with the different crops. It was lowest in the first and highest in the third crop. Apparently a profuse growth resulted in a decreased percentage of nitrogen. Jars 1 and 2, the first crop, contained 3.86 per cent of nitrogen and jars 11 and 12, 4.17 per cent. Lime and inoculation proved very beneficial. The differences in precentage of nitrogen in the other two crops were not so pronounced. Half lime plus inoculation was equally as effective as full lime plus inoculation in increasing the percentage of nitrogen in the crops. The roots did not show any consistent benefit from inoculation or lime.

In Table III are presented summary data showing the results of the alfalfa experiment. The figures of the table give

the average weight and nitrogen content of all crops in grams and the relative weight in pounds per acre (9). The beneficial effect of inoculation is marked not only by a greater yield, but also by a greater gain in nitrogen. Since the same number of plants were grown in each jar, the increase must be due to a greater growth of the individual plant (2, p. 182).

TABLE III.—EFFECT OF TREATMENT ON GROWTH AND NITROGEN FIXATION BY ALFALFA ON COLBY SILT LOAM

Pot No.		Dry weight		Total nitrogen			Increase in total nitrogen due to treatment			
		Average for duplicate jars	Per acre	Average for duplicate jars	Per acre		Milligrams for duplicate jar		Per acre	
						Total	Tops	Tops and roots	Tops	Tops and roots
		Gms.	Lbs.	Mgm.	Lbs.	Lbs.			Lbs.	Lbs.
1	Tops	24.33	3892.8	990.35	158.46					
2	Roots	19.27	3083.2	578.65	92.58	251.04				
3	Tops	26.26	4201.6	1115.45	178.47		125.1		20.01	
4	Roots	16.76	2681.6	504.8	80.77	259.24		51.3		8.20
5	Tops	25.21	4033.6	1088.26	174.12		97.9		15.66	
6	Roots	19.86	3177.6	577.95	92.47	266.59		97.2		15.55
7	Tops	28.66	4585.6	1254.58	200.73		264.2		42.27	
8	Roots	24.71	3953.6	715.9	114.54	315.27		401.5		64.23
9	Tops	26.40	4224.0	1078.74	172.60		88.4		14.14	
10	Roots	23.40	3744.0	674.3	107.89	280.49		184.1		29.45
11	Tops	31.69	5070.4	1363.43	218.15		373.1		59.69	
12	Roots	18.98	3036.8	574.05	91.85	310.00		368.4		58.96

The increase in total nitrogen due to inoculation alone was 20.1 pounds per acre, to full lime inoculation, 59.69 pounds. Lime treatment alone failed to cause any decided gain in the yield of dry matter or the amount of nitrogen.

The effect of the different treatments is shown very clearly in the columns of Figure 4. The yield of dry matter, the total nitrogen content, and the percentage of nitrogen in dry matter were increased by inoculation.

NITROGEN CONTENT OF SOY BEANS

The results of Table II show the marked beneficial influence of inoculation on the precentage of nitrogen in soy beans. This is true both in the first and second crops. Unlike the experiments with alfalfa, it was found that lime alone did not increase the percentage of nitrogen in soy beans.

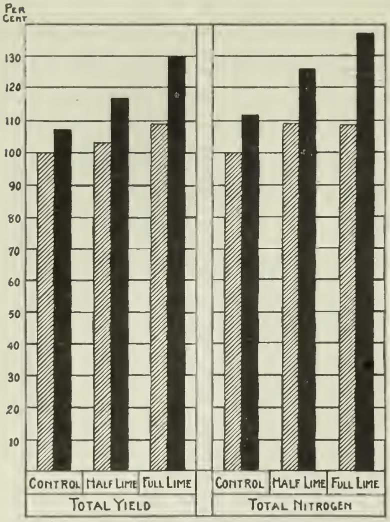

FIG. 4.—GROWTH AND NITROGEN CONTENT OF ALFALFA ON COLBY SILT LOAM

The checked columns denote uninoculated and the dark columns inoculated.

In order to show the effect of treatment on the yield of dry matter and quanity of nitrogen in the crops of soy beans, the data of Table II are presented in summary form in Table IV. The results show a large increase in nitrogen in all of the inoculated jars. This amounted to 39.0 per cent in the case of jars 3 and 4. The maximum amount of nitrogen was found in the crop taken from soil receiving the largest application of lime. This agrees with the results of Lipman and his associates (11) who noted that lime increases the nitrogen content of soy beans. Apparently in Colby silt loam soil inoculation is more important than lime for the first two crops of soy beans. A summary of the results of the preceding table is shown in Figure 5.

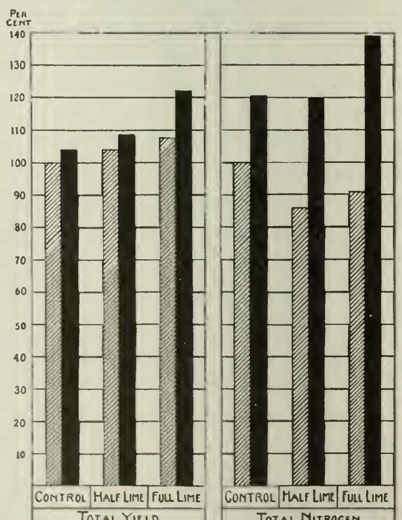

FIG. 5.—GROWTH AND NITROGEN CONTENT OF SOY BEANS ON COLBY SILT LOAM

The checked columns denote uninoculated and the dark columns inoculated.

RESULTS OF POT EXPERIMENTS FOR 1915

The same general plan was followed as in the previous experiments. However, the study was extended to include two soil types, acid Colby silt loam taken from the same place as the soil used in the previous tests, and acid Plainfield sand.

Two different crops were grown on each soil type, alfalfa and red clover.

The soils were collected in the fall of 1914, carefully potted and various amounts of lime added. In all of the experiments, carbonate of lime was applied in amounts sufficient to neutralize one-half and all of the soil acidity according to the Truog (18) method. Colby silt loam jars, 5 to 8 inclusive, received 0.52 gram per 100 grams of soil, jars 9 to 12

TABLE IV.—EFFECT OF TREATMENT ON GROWTH AND NITROGEN FIXATION BY SOY BEANS ON COLBY SILT LOAM

Group No.	Dry weight		Total nitrogen		Increase in total nitrogen due to treatment	
	Average for duplicate jars	Per acre	Average for duplicate jars	Per acre	Average for duplicate jars	Per acre
	Gms.	Lbs.	Mgm.	Lbs.	Mgm.	Lbs.
1	31.68	5,068.8	1,026.79	164.29		
2	33.17	5,307.2	1,238.65	198.18	211.86	33.89
3	32.95	5,272.0	897.90	143.66	-128.90	-20.63
4	34.75	5,560.0	1,236.55	197.85	210.00	33.56
5	33.98	5,436.8	954.70	152.75	-72.00	-11.54
6	38.75	6,200.0	1,427.50	228.40	400.70	64.11

inclusive, of the same series, received 1.04 grams per 100 grams of soil. The Truog method shows much larger amounts of soil acidity than the Veitch. Plainfield sand jars, 5 to 8 inclusive, received 0.26 gram per 100 grams of soil, jars 9 to 12 inclusive, 0.52 gram. In addition to the carbonate of lime treatment, the sand series received on April 17 an application of 0.25 gram of dibasic potassium phosphate per kilogram of dry sand.

THE EFFECT OF TREATMENT ON THE YIELD OF ALFALFA AND RED CLOVER

February 16, 1915, two series of 12 jars each, Colby silt loam and Plainfield sand, were planted to alfalfa. The seedlings in one-half of the jars of each series were thoroughly inoculated, the other half were kept as free from alfalfa bacteria as possible. Two weeks later, the other series of 12 jars each, Colby silt loam and Plainfield sand, were planted to clover. The same plan was followed as in the alfalfa experiments. In all cases 25 plants were allowed to mature.

Weather conditions were unusually favorable for greenhouse work. Five crops were harvested from each of the alfalfa series on the following dates: April 28, June 9, July 12, August 21, and September 22. After the last crop was harvested, the roots were carefully removed, notes taken on nodule formation, and the tissue kept for analysis. Because of the large number of very fine rootlets, it was found very difficult to remove all of the roots from the soil. The different crops were also dried and kept for analysis. The soils were mixed thoroughly and samples were drawn for analysis.

From the two clover series, three crops were harvested as follows: June 1, July 12, and September 22. After the last crop was cut, the soils were removed from the pots, the roots examined for nodules and then returned to the soil. This procedure was necessary in order to secure decomposition of the root tissue before sampling the soils. No attempt was made to measure the nitrogen content of the clover roots. After decomposition had taken place, three months later, the soils were sampled in the same manner as the soils from the alfalfa series.

YIELD OF ALFALFA ON COLBY SILT LOAM

In Table V are recorded the dry weights of the five alfalfa crops, the roots as well as the total nitrogen and the percentage of nitrogen of each crop. The treated jars show a large and uniform increase in yield of dry matter, which is well marked in each one of the five crops. In the no-lime series, the beneficial effect of inoculation on plant growth became more noticeable with the successive crops. The greatest difference was found in the fifth crop. Here the inoculated series produced more than double as much alfalfa as the uninoculated control, or an increase of 120.3 per cent. The average weight of dry matter for duplicate pots, including five crops, was as follows:

Control uninoculated	34.36 grams
Control inoculated	49.77 grams
One-half lime uninoculated	59.88 grams
One-half lime inoculated	65.18 grams
Full lime uninoculated	61.38 grams
Full lime inoculated	67.39 grams

It is significant that half lime should produce almost as great a yield of dry matter as the full amount required to

TABLE V.—THE INFLUENCE OF INOCULATION WITH AND WITHOUT LIME ON GROWTH AND NITROGEN CONTENT OF ALFALFA ON COLBY SILT LOAM

Pot No.	Dry weight of different crops						Nitrogen in different crops											
	Tops 1	Tops 2	Tops 3	Tops 4	Tops 5	Roots	Tops 1	Tops 2	Tops 3	Tops 4	Tops 5	Roots	Tops 1	Tops 2	Tops 3	Tops 4	Tops 5	Roots
	Gms.	Gms.	Gms.	Gms.	Gms.	Gms.	Mgm.	Mgm.	Mgm.	Mgm.	Mgm.	Mgm.	P. Ct.	P. Ct.	P. Ct.	P. Ct.	P. Ct.	P. Ct.
1	5.34	11.55	8.33	4.49	4.48	15.02	280.4	417.5	209.9	112.7	139.6	164.8	5.25	3.62	2.52	2.51	3.12	1.10
2	4.58	10.90	10.00	4.36	4.68	23.95	246.0	429.1	271.7	111.7	147.0	240.2	5.37	3.93	2.72	2.56	3.14	1.00
Av.	4.96	11.22	9.16	4.42	4.58	19.48	263.2	423.3	204.8	112.2	143.3	202.5	5.31	3.77	2.62	2.53	3.13	1.05
3	5.45	11.34	13.86	8.06	9.14	21.30	291.1	484.3	557.6	289.1	362.6	411.7	5.34	4.27	4.02	3.59	3.97	1.93
4	5.55	12.26	14.31	8.51	11.05	16.45	299.4	474.1	579.4	333.3	448.4	294.8	5.39	3.87	4.05	3.92	4.06	1.79
Av.	5.50	11.80	14.08	8.28	10.09	18.87	295.2	479.2	568.5	311.2	405.5	353.2	5.36	4.07	4.03	3.75	4.01	1.86
5	6.26	13.43	19.13	10.98	10.09	15.03	313.8	524.9	784.8	408.0	428.3	287.8	5.01	3.91	4.10	3.72	4.25	1.92
6	7.33	14.01	17.64	10.88	10.00	15.37	372.9	541.9	717.9	405.8	391.1	262.7	5.09	3.86	4.07	3.73	3.91	1.71
Av.	6.79	13.72	18.38	10.93	10.04	15.20	343.3	533.4	751.3	406.9	409.7	275.2	5.05	3.88	4.08	3.72	4.04	1.81
7	7.24	14.01	20.03	11.62	14.04	17.23	375.6	573.0	772.4	423.6	571.7	321.0	5.18	4.09	3.86	3.65	4.07	1.86
8	8.62	13.50	18.77	10.26	12.27	15.19	462.9	540.4	694.1	386.8	481.2	289.4	5.37	4.00	3.70	3.77	3.92	1.91
Av.	7.93	13.75	19.40	10.94	13.15	16.21	419.2	556.7	733.2	405.2	526.4	305.2	5.27	4.04	3.78	3.71	3.99	1.88
9	7.21	12.98	18.10	11.16	12.94	14.61	377.0	554.9	745.0	409.0	526.0	273.9	5.23	4.28	4.12	3.67	4.07	1.86
10	7.41	12.69	17.80	10.68	11.79	25.78	376.1	523.5	719.7	400.1	500.6	507.4	5.07	4.13	4.04	3.75	4.25	1.97
Av.	7.31	12.83	17.95	10.92	12.36	20.19	376.5	539.2	732.3	404.5	513.3	390.6	5.15	4.20	4.08	3.71	4.16	1.91
11	7.75	13.35	18.40	11.16	13.29	17.47	402.5	559.6	726.0	423.9	529.1	329.8	5.19	4.19	3.95	3.80	3.98	1.89
12	8.41	16.68	19.66	12.95	13.13	16.54	415.2	663.4	742.9	472.7	503.9	312.4	4.94	3.97	3.78	3.65	3.84	1.89
Av.	8.08	15.01	19.03	12.05	13.21	17.00	408.8	611.5	734.4	448.3	516.5	321.1	5.06	4.08	3.86	3.72	3.91	1.89

neutralize soil acidity. This is true of each one of the five crops. Somewhat similar results have been reported from other stations.

For example, Hopkins of Illinois (10) reports that moderate quantities of calcium carbonate applied to acid soils greatly favor the growth of legumes.

According to Frear (7) the growth of red clover on acid soil is greatly benefited when the acidity is only partially neutralized.

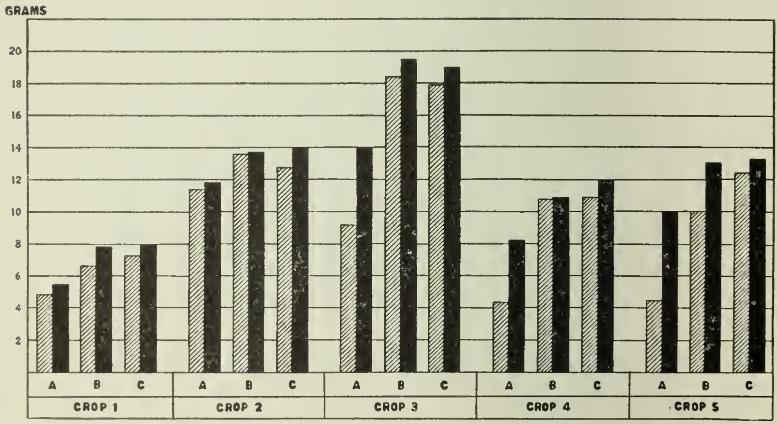

FIG. 6.—GROWTH OF ALFALFA ON COLBY SILT LOAM

a. Control; b. half lime; c. full lime. The checked columns denote uninoculated and the dark columns inoculated.

Lipman (12) found that lime increases the yield of dry matter of crimson clover and likewise the percentage of nitrogen. Small quantities of lime produced nearly as great yields as large quanties of lime.

In regard to the activity of the soil bacteria, Scales (16) found that according to the Veitch method the nitrifying and ammonifying bacteria were most active in the presence of 50 to 75 per cent of the calcium carbonate requirement. From the data of Table V, it appears that smaller quantities of lime than those indicated by the Truog method will give almost maximum results.

The quantity of lime required to produce a good growth of legumes is one of the important problems of scientific agriculture. If just half enough to neutralize soil acidity

is all that is needed, as indicated by the foregoing data, then it is well to bring this point to the attention of the farmers.

The effect of treatment on the differences in yield of dry matter is brought out very clearly in the columns of Figure 6.

YIELD OF ALFALFA ON PLAINFIELD SAND

With the exception of soil type and the addition of a potassium and phosphate fertilizer, the conditions of this experiment were the same as those of alfalfa in Colby silt loam

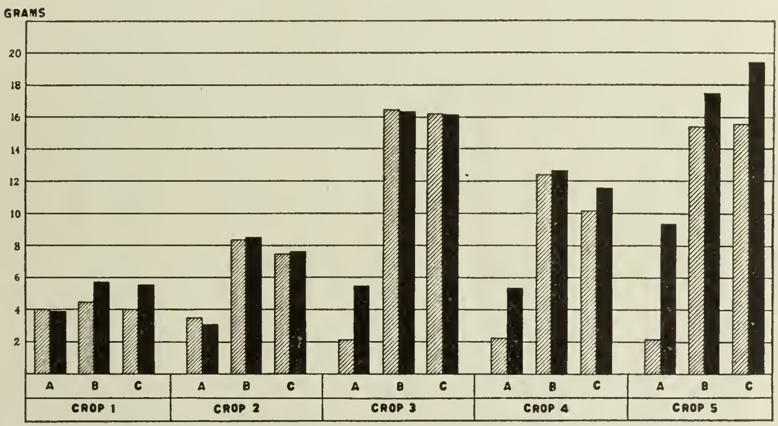

FIG. 7.—GROWTH OF ALFALFA ON PLAINFIELD SAND

a. Control; b. half lime; c. full lime. The checked columns denote uninoculated and the dark columns inoculated.

soil. The results of all nitrogen determinations, as well as dry weights, are expressed in Table VI. The influence of inoculation was noticeable in the first two cuttings, and very marked in the third, fourth, and fifth cuttings. The differences in development of inoculated alfalfa, with and without lime, are shown in Plate I. The maximum benefit from inoculation was obtained in the last crop. Plates II and III illustrate the influence of inoculation on alfalfa in Plainfield sand. The roots shown in Plate III were taken from the plants shown in Plate II. In this case, alfalfa on Plainfield sand, the effect of inoculation was particularly great. A sum-

TABLE VI.—THE INFLUENCE OF INOCULATION WITH AND WITHOUT LIME ON GROWTH AND NITROGEN CONTENT OF ALFALFA ON PLAINFIELD SAND

Pot No.	Dry weight of different crops						Nitrogen in different Crops											
	Tops 1	Tops 2	Tops 3	Tops 4	Tops 5	Roots	Tops 1	Tops 2	Tops 3	Tops 4	Tops 5	Roots	Tops 1	Tops 2	Tops 3	Tops 4	Tops 5	Roots
	Gms.	Gms.	Gms.	Gms.	Gms.	Gms.	Mgm.	Mgm.	Mgm.	Mgm.	Mgm.	Mgm.	P. Ct.	P. Ct.	P. Ct.	P. Ct.	P. Ct.	P. Ct.
1	4.31	3.60	2.50	2.25	2.36	5.23	209.6	108.8	70.7	63.9	58.3	65.3	4.86	3.02	2.83	2.84	2.47	1.25
2	3.78	3.36	1.66	2.25	2.00	7.59	151.4	95.4	53.7	60.1	54.1	92.8	4.00	2.83	3.23	2.67	2.70	1.22
Av.	4.04	3.48	2.08	2.25	2.18	6.41	180.5	102.1	62.2	62.0	56.2	79.0	4.43	2.92	3.03	2.75	2.58	1.23
3	4.35	3.00	4.88	4.94	8.58	11.32	194.8	107.5	166.9	156.2	296.4	212.1	4.48	3.58	3.42	3.16	3.46	1.87
4	3.50	3.00	6.20	5.82	10.54	12.64	156.8	109.5	225.1	184.2	251.9	243.6	4.48	3.65	3.63	3.17	3.34	1.93
Av.	3.92	3.00	5.54	5.38	9.56	11.98	175.8	108.5	196.0	170.2	324.1	227.8	4.48	3.61	3.52	3.16	3.40	1.90
5	4.83	8.13	16.40	12.96	15.05	28.22	221.8	291.5	564.2	413.3	505.7	589.5	4.59	3.59	3.44	3.19	3.36	2.09
6	4.12	8.54	16.89	12.31	16.07	22.85	209.1	338.1	577.9	397.0	548.5	468.4	5.08	3.96	3.42	3.23	3.41	2.05
Av.	4.47	8.33	16.64	12.63	15.56	25.53	215.4	314.8	571.0	405.1	527.1	528.9	4.83	3.77	3.43	3.21	3.38	2.07
7	5.54	8.16	15.70	12.06	17.89	23.04	286.9	311.9	520.8	353.4	585.0	473.2	5.18	3.82	3.32	2.93	3.27	2.05
8	5.96	8.72	16.86	13.42	17.38	20.50	285.5	350.2	619.3	438.8	590.1	434.2	4.79	4.01	3.67	3.27	3.39	2.12
Av.	5.75	8.44	16.28	12.74	17.63	21.77	286.2	331.0	570.0	396.1	587.5	453.7	4.98	3.91	3.49	3.10	3.33	2.08
9	3.88	7.74	17.37	10.75	16.40	23.51	193.1	309.4	571.7	333.1	546.9	481.9	4.98	3.99	3.29	3.10	3.34	2.05
10	4.33	7.27	15.09	9.55	15.14	23.46	218.8	281.8	472.5	310.5	538.7	484.5	5.05	3.87	3.13	3.25	3.56	2.07
Av.	4.10	7.50	16.23	10.15	15.77	23.48	205.9	295.6	522.1	321.8	542.8	483.2	5.01	3.93	3.21	3.17	3.45	2.06
11	5.16	7.27	15.49	12.77	18.87	21.81	246.2	288.0	507.8	441.7	650.4	505.3	4.77	3.96	3.28	3.46	3.45	2.32
12	5.89	7.86	16.84	10.26	20.14	24.54	294.3	309.8	576.4	314.3	663.0	528.8	4.99	3.94	3.42	3.06	3.29	2.16
Av.	5.52	7.56	16.16	11.51	19.50	23.17	270.2	298.9	542.1	378.0	656.7	517.0	4.88	3.95	3.35	3.26	3.37	2.24

mary of the effect of the various treatments on production of dry matter is shown below:

Control uninoculated	14.04 grams
Control inoculated	27.41 grams
One-half lime uninoculated	57.65 grams
One-half lime inoculated	60.85 grams
Full lime uninoculated	53.76 grams
Full lime inoculated	60.28 grams

Here again, one-half lime gives equally as large yields as full lime. It is apparent from the data of these two experiments that small quantities of lime are more economical in improving crop production than quantities great enough to neutralize all soil acidity. A comparison of the total weights

TABLE VII.—THE INFLUENCE OF INOCULATION WITH AND WITHOUT LIME ON GROWTH AND NITROGEN CONTENT OF CLOVER ON COLBY SILT LOAM

Pot No.	Dry Weight of Different Crops			Nitrogen in Different Crops					
	Tops 1	Tops 2	Tops 3	Tops 1	Tops 2	Tops 3	Tops 1	Tops 2	Tops 3
	Gms.	Gms.	Gms.	Mgm.	Mgm.	Mgm.	P. Ct.	P. Ct.	P. Ct.
1	15.29	17.94	21.60	547.4	698.9	674.1	3.58	3.90	3.12
2	17.84	19.84	20.62	639.9	770.4	665.6	3.58	3.88	3.23
Av.	16.56	18.89	21.11	593.6	734.6	669.8	3.58	3.89	3.17
3	20.32	17.63	19.09	754.7	716.8	626.7	3.71	4.07	3.28
4	19.40	17.68	16.95	716.3	703.5	551.6	3.69	3.98	3.26
Av.	19.86	17.65	18.02	735.5	710.1	589.1	3.70	4.02	3.27
5	19.78	17.74	24.20	768.5	696.2	803.7	3.88	3.92	3.32
6	21.17	17.99	24.94	798.7	669.6	822.0	3.77	3.72	3.30
Av.	20.47	17.86	24.57	783.6	682.9	812.8	3.82	3.82	3.31
7	20.43	16.63	20.88	794.1	656.4	706.4	3.88	3.95	3.38
8	21.35	18.52	21.29	843.3	754.3	739.0	3.95	4.07	3.47
Av.	20.89	17.57	21.08	818.7	705.3	722.7	3.91	4.01	3.42
9	17.80	16.28	25.13	700.3	681.6	853.4	3.93	4.19	3.40
10	20.53	17.26	26.17	806.2	705.2	887.7	3.93	4.09	3.39
Av.	19.16	16.77	25.65	753.2	693.4	870.5	3.93	4.14	3.39
11	23.13	18.61	22.57	875.5	719.7	727.9	3.78	3.87	3.23
12	21.35	20.69	23.60	858.4	817.3	774.1	4.01	3.95	3.28
Av.	22.24	19.65	23.08	866.9	768.5	751.0	3.89	3.91	3.25

of all five crops shows that lime alone in Plainfield sand was nearly as efficient in stimulating plant growth as lime plus inoculation.

In order to show more clearly the effect of the various treatments on plant growth, a summary of the data of Table VI is shown in Figure 7.

YIELD OF CLOVER ON COLBY SILT LOAM

In Table VII data are given which show the dry weights for all crops, and the total nitrogen analyses. Unlike the preceding experiments with alfalfa or soy beans, treatment did not cause any consistent gain in yield of dry matter. With the exception of jars 7 and 8, the first crop apparently received all of the benefit from the use of lime and inoculation. Inoculation alone produced an increase of 3.3 grams or 19.9 per cent. Full lime with inoculation increased crop growth by 5.68 grams or 34.3 per cent. The other two crops failed to show much benefit from the treatment.

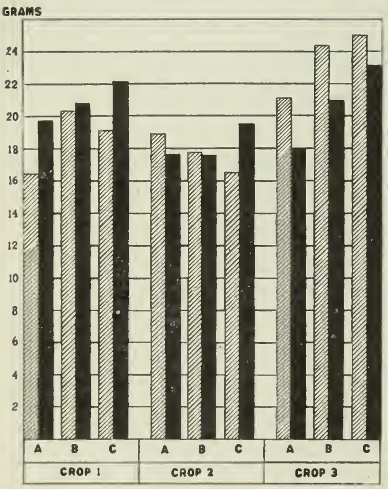

FIG. 8.—GROWTH OF CLOVER ON COLBY SILT LOAM

a. Control; b. half lime; c. full lime. The checked columns denote uninoculated and the dark columns inoculated.

The total yield of the three crops did not show a gain due to inoculation alone. The maximum total yield was obtained from the use of full lime and inoculation. Here the increase was 8.41 grams or 14.8 per cent. Although this soil is decidedly acid, it seems well suited for the growth of red clover. The results from Colby silt loam do not agree with those obtained with Maryland soil. Veitch (20) observed that red clover does not thrive well on Maryland soil with a lime requirement of eight to twelve hundred pounds of lime per acre. The percentage gain from treatment is low when compared with yields obtained with alfalfa. In Figure 8 the yields of different crops are shown by a series of columns.

YIELD OF CLOVER ON PLAINFIELD SAND

The data presented in Table VIII are similar to those of clover on Colby silt loam.

Inoculation alone gave an increased crop production. The increase was most noticeable in the first crop, amounting to 30.6 per cent more than was obtained in the control jars 1 and 2. Inoculated with full lime, first crop, jars 11 and 12, gave an increased growth of 11.08 grams or 106.6 per cent. In every case the first crop was most benefited by the treat-

TABLE VIII.—THE INFLUENCE OF INOCULATION WITH AND WITHOUT LIME ON GROWTH AND NITROGEN CONTENT OF CLOVER ON PLAINFIELD SAND

Pot No.	Dry Weight of Different Crops			Nitrogen in Different Crops					
	Tops 1	Tops 2	Tops 3	Tops 1	Tops 2	Tops 3	Tops 1	Tops 2	Tops 3
	Gms.	Gms.	Gms.	Mmg.	Mgm.	Mgm.	P. Ct.	P. Ct.	P. Ct.
1	10.48	17.75	18.99	334.6	679.0	557.4	3.19	3.83	2.94
2	10.30	16.59	23.00	334.5	643.2	660.3	3.25	3.88	2.87
Av.	10.39	17.17	20.99	334.5	661.1	608.8	3.22	3.85	2.90
3	13.94	17.45	23.32	599.8	712.3	620.9	4.31	4.08	2.66
4	13.21	16.55	23.26	564.9	705.0	688.5	4.27	4.26	2.96
Av.	13.57	17.00	23.29	582.3	708.6	654.7	4.29	4.17	2.81
5	17.72	24.55	31.29	704.2	920.9	871.4	3.97	3.75	2.79
6	17.91	22.49	32.58	687.9	832.8	930.7	3.84	3.70	2.86
Av.	17.81	23.52	31.93	696.0	876.8	901.0	3.90	3.72	2.82
7	18.94	22.65	37.52	755.3	867.3	1,038.6	3.98	3.83	2.77
8	19.68	21.76	33.03	793.9	848.7	925.5	4.03	3.90	2.80
Av.	19.31	22.20	35.27	774.6	858.0	982.0	4.00	3.86	2.78
9	17.19	20.98	32.29	617.3	717.1	832.1	3.59	3.42	2.58
10	20.77	19.69	30.35	807.9	732.9	846.5	3.89	3.72	2.79
Av.	18.98	20.33	31.32	712.6	725.0	839.3	3.74	3.57	2.68
11	19.88	22.65	37.56	783.7	824.7	1,039.3	3.94	3.64	2.77
12	23.06	20.67	30.35	884.4	710.2	779.4	3.83	3.44	2.57
Av.	21.47	21.66	33.95	834.0	767.4	909.3	3.88	3.54	2.67

ment. The increased growth due to treatment is shown in Plate IV.

The total yields of all crops weighed more in the treated, than in the untreated jars. The increase due to inoculation alone was 5.31 grams or 10.9 per cent. The greater yield due to inoculation with full lime was 28.53 grams or 58.7 per cent. Lime and inoculation are accordingly very beneficial in producing maximum yields of clover on acid Plainfield sand. This is shown very clearly by Figure 9.

THE EFFECT OF TREATMENT ON THE NITROGEN CONTENT OF ALFALFA AND CLOVER

The data herewith presented were taken from the figures of Tables V and VI. Here only the summary tables will be shown.

NITROGEN CONTENT OF ALFALFA ON COLBY SILT LOAM

According to the results of Table V the percentage of nitrogen in the different cuttings varied widely. It was greatest in the first and smallest in the fifth crop. As a rule, a small yield of dry matter is accompanied by a high percentage of nitrogen. For example, inoculation alone caused a great increase in the percentage of nitrogen. The average percentage of nitrogen in five crops, jars 1 and 2 uninoculated was 3.47; in jars 3 and 4 inoculated was 4.25. Lime alone caused a slight gain in the percentage of nitrogen, although much less than inoculation. In view of the increased yield of dry matter in the limed series, it is not surprising that the percentage of nitrogen was smaller than in the inoculated series.

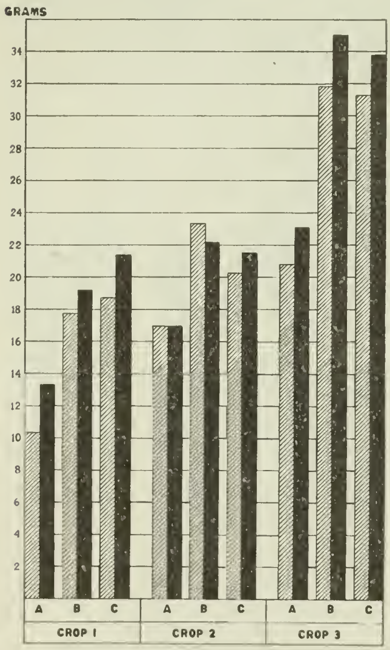

FIG. 9.—GROWTH OF CLOVER ON PLAINFIELD SAND

a. Control; b. half lime; c. full lime. the checked columns denote uninoculated and the dark columns inoculated.

The beneficial effect of treatment on the total nitrogen of alfalfa is shown in summary Table IX. From the results of the table it will be seen that jars 1 and 2, uninoculated, contained 1,182.8 milligrams of nitrogen, while jars 3 and 4, inoculated, contained 2,059.65 milligrams, a difference of 876.8 milligrams in favor of inoculation. Calculated in terms of pounds, the increase is equivalent to 140.3 pounds per acre. If it is assumed that all of the nitrogen in the uninoculated plants was taken from the soil, and that an equivalent quantity of nitrogen in the inoculated plants was taken from the soil, then there is a gain of 140.3 pounds of atmospheric nitrogen. Inoculation and full lime gave the greatest yield and highest quantity of nitrogen. The crop from jars

11 and 12 contained 2,719.6 milligrams of nitrogen or 1,536.8 milligrams more than was contained in the control. This is the equivalent of 245.9 pounds of nitrogen per acre. If the roots are taken into consideration, then a maximum increase of 264.9 pounds was obtained.

The proportion of nitrogen in the tops to that in the roots increases with the treatment. In the control crops the proportion was about 6 to 1. In the crops from jars 11 and 12 the proportion was about 8 to 1, a considerable variation

TABLE IX.—EFFECT OF TREATMENT ON GROWTH AND NITROGEN FIXATION BY ALFALFA ON COLBY SILT LOAM

Pot No.		Dry Weight		Total nitrogen			Increase in total nitrogen due to treatment			
		Average for duplicate jars	Per acre	Average for duplicate jars	Per acre		Milligrams for duplicate jars		Per acre	
						Total	Tops	Tops and Roots	Tops	Tops and Roots
		Gms.	Lbs.	Mgm.	Lbs.	Lbs.			Lbs.	Lbs.
1	Tops	34.36	5,497.6	1,182.8	189.2					
2	Roots	19.49	3,118.4	202.5	32.40	221.6				
3	Tops	49.77	7,963.2	2,059.65	329.5		876.8		140.3	
4	Roots	18.88	3.020.8	353.25	56.52	386.0		1,027.6		164.4
5	Tops	59.88	9,580.8	2,444.75	391.20		1,261.9		202.0	
6	Roots	15.20	2,432.0	275.25	44.00	435.2		1,334.7		213.6
7	Tops	65.18	10,428.8	2,640.85	422.50		1,458.0		233.3	
8	Roots	16.21	2,593.6	305.2	48.80	471.3		1,560.7		249.7
9	Tops	61.38	9,820.8	2,565.95	410.60		1,383.1		221.4	
10	Roots	20.20	3,232.0	390.65	62.50	473.1		1,571.3		251.5
11	Tops	67.39	10,782.4	2,719.60	435.10		1,536.8		245.9	
12	Roots	17.00	2,720.0	321.1	51.40	486.5		1,655.4		264.9

from that of the controls. Figure 10 shows very clearly the marked beneficial effect of treatment on crop growth and nitrogen content.

NITROGEN CONTENT OF ALFALFA ON PLAINFIELD SAND

The effect of the treatment on the total nitrogen and the dry matter of alfalfa is shown in the data of Table VI. Since the crop yield of the first cutting was much lower than any of the others, as might be expected, the percentage of nitrogen was highest. The average percentage gain of all five crops inoculated, jars 3 and 4, was 0.49, while the gain for

the inoculated series, full lime, was 0.62. Aside from the increase in percentage of nitrogen, inoculation caused an enormous increase in total milligrams of nitrogen. As in the case of Colby silt loam, the gain is very large, especially in the fifth crop, in the treated series. The gain due to inoculation alone amounted to 267.9 milligrams or 476.6 per cent; inoculation full lime 600.5 milligrams or 1068.5 per cent. The first crop, full lime and inoculation, gave a gain of 89.75 milligrams or 49.7 per cent. It seems that the longer the lime can act on the plant and organism, the greater the benefit derived.

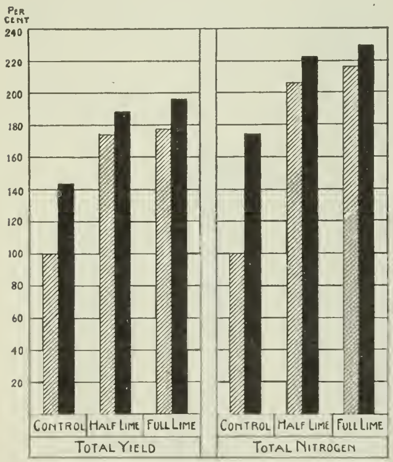

Fig. 10.—GROWTH AND NITROGEN FIXATION OF ALFALFA ON COLBY SILT LOAM

The checked columns denote uninoculated and the dark columns inoculated.

It is evident from the data in Table X that treatment was very effective in producing not only much greater yields, but also in fixing considerable atmospheric nitrogen. The full lime crops from jars 11 and 12 weighed over four times as much as the crops from jars 1 and 2.

Inoculation alone caused a fixation of 511.6 milligrams of nitrogen or at the rate of 81.8 pounds per acre. This rate was increased to 105.7 pounds if the roots are taken into consideration. The maximum increase was secured in the crops grown in the inoculated series with full lime, jars 11 and 12, where a total increase of 2121.0 milligrams of nitrogen was found. This increase is at the rate of 339.4 pounds per acre. In general it may be said that practically as good results were obtained from the half lime treatment as from the full lime treatment. A summary of the data in the previous table is given in Figure 11.

NITROGEN CONTENT OF CLOVER ON COLBY SILT LOAM

A review of the results of Table VII shows that the percentage of nitrogen varied greatly. In general the per-

TABLE X.—EFFECT OF TREATMENT ON GROWTH AND NITROGEN FIXATION BY ALFALFA ON SPARTA SAND

Pot No.		Dry Weight		Total nitrogen			Increase in total nitrogen due to treatment			
		Average for duplicate jars	Per acre	Average for duplicate jars	Per acre		Milligrams for duplicate jars		Per acre	
						Total	Tops	Tops and Roots	Tops	Tops and Roots
		Gms.	Lbs.	Mgm.	Lbs.	Lbs.			Lbs.	Lbs.
1	Tops	14.04	2,246.4	463.0	74.1					
2	Roots	6.41	1,025.6	79.05	12.6	86.7				
3	Tops	27.41	4,385.6	974.65	155.9		511.6		81.8	
4	Roots	11.98	1,916.8	227.85	36.5	192.4		660.5		105.7
5	Tops	57.65	9,224.0	2,033.55	325.4		1,570.5		251.3	
6	Roots	25.54	4,086.4	528.95	84.6	410.0		2,020.5		323.3
7	Tops	60.85	9,736.0	2,170.95	347.4		1,707.9		273.3	
8	Roots	21.77	3,483.2	453.70	72.6	420.0		2,082.6		333.3
9	Tops	53.76	8,601.6	1,888.25	302.1		1,425.2		228.0	
10	Roots	23.49	3,758.4	483.20	77.3	379.4		1,829.4		292.7
11	Tops	60.28	9,644.8	2,145.95	343.4		1,682.9		269.3	
12	Roots	23.18	3,708.8	517.05	82.7	426.1		2,121.0		339.4

centage of nitrogen was higher in the first crop than in the other two crops. The treated series showed only a slight increase in percentage of nitrogen. Inoculation alone resulted in a gain in total nitrogen of 23.8 per cent, while inoculation full lime, a gain of 46.0 per cent. These differences were found in the first crop. The second and third crops failed to respond to inoculation. A record of the total yield of dry matter and of total nitrogen is presented in Table XI. The results of the table are not in agreement with those obtained with alfalfa on Colby silt loam soil. In general, inoculation failed to increase crop yield. Apparently Colby soil is well supplied with active clover bacteria.

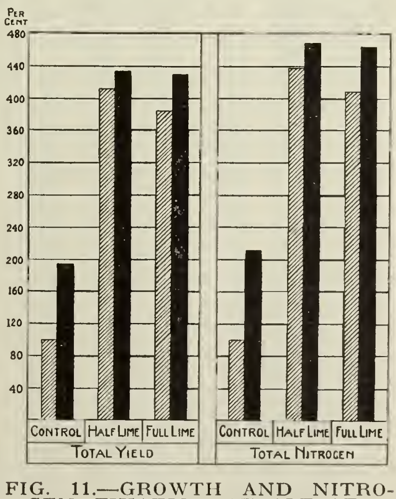

FIG. 11.—GROWTH AND NITROGEN FIXATION OF ALFALFA ON PLAINFIELD SAND

The checked columns denote uninoculated and the dark columns inoculated.

TABLE XI.—EFFECT OF TREATMENT ON GROWTH AND NITROGEN FIXATION BY CLOVER ON COLBY SILT LOAM

Pot No.	Dry weight		Total nitrogen		Increase in total nitrogen due to treatment	
	Average for duplicate jars	Per acre	Average for duplicate jars	Per acre	Per acre	Average for duplicate jars
	Gms.	Lbs.	Mgm.	Lbs.	Lbs.	Mgm.
1	56.57	9,051.2	1,998.15	319.7		
2	55.54	8,886.4	2,034.80	325.6	5.9	36.7
3	62.91	10,065.6	2,279.35	364.7	45.0	281.2
4	59.55	9,528.0	2,246.75	359.5	39.8	248.6
5	61.59	9,354.4	2,317.20	370.7	51.0	319.2
6	64.98	10,396.8	2,386.45	381.8	62.1	388.3

The addition of lime caused as light stimulation in the growth of clover. A review of the data is given in Figure 12.

NITROGEN CONTENT OF CLOVER ON PLAINFIELD SAND

It is clear from the data in Table VIII that the highest percentage of nitrogen is generally found in the first crop. The percentage gain for inoculation, all crops, was 0.43. Inoculation alone produced an increased yield of dry matter of 74 per cent. Inoculation plus lime gave the greatest gain, 149.3 per cent. Apparently lime and inoculation are very beneficial to the growth of clover on Plainfield sand. This is brought out by the results of Table XII. Figure 13 also shows the benefit of treatment on the growth of clover.

It is clear from the figures that treatment was much more effective on the clover crops grown on Plainfield sand than on the clover crops grown on Colby silt loam. The greatest increase in yield was obtained from jars 11 and 12.

TABLE XII.—EFFECT OF TREATMENT ON GROWTH AND NITROGEN FIXATION BY CLOVER ON SPARTA ACID SAND

Pot No.	Dry weight		Total nitrogen		Increase in total nitrogen due to treatment	
	Average for duplicate jars	Per acre	Average for duplicate jars	Per Acre	Per acre	Average for duplicate jars
	Gms.	Lbs.	Mgm.	Lbs.	Lbs.	Mgm.
1	48.56	7,769.6	1,604.50	256.7		
2	53.87	8,619.2	1,945.70	311.3	54.6	341.2
3	73.27	11,723.2	2,473.95	395.8	139.1	869.4
4	76.79	12,286.4	2,614.65	418.3	161.6	1,010.1
5	70.64	11,302.4	2,276.90	364.3	107.6	672.4
6	77.09	12,334.4	2,510.85	401.7	145.0	906.3

Inoculation alone increased the amount of nitrogen in the crops. The increase was 341.2 milligrams per jar or at the rate of 54.6 pounds per acre. The greatest increase was secured in the crops grown in jars 7 and 8 where 1010.1 milligrams more nitrogen were found than in the control crops. This increase is at the rate of 161.6 pounds per acre or 62.9 per cent. Treatment was therefore very beneficial in producing large yields and in securing large amounts of nitrogen from the atmosphere.

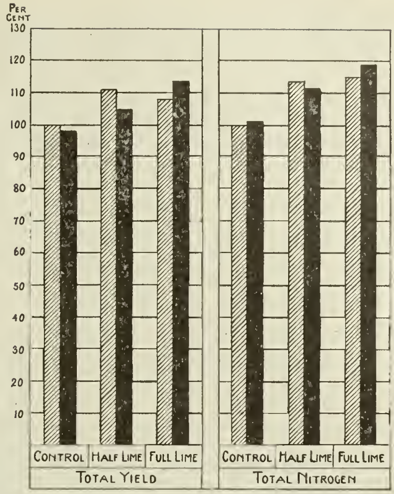

FIG. 12.—GROWTH AND NITROGEN FIXATION OF CLOVER ON COLBY SILT LOAM

The checked columns denote uninoculated and the dark columns inoculated.

THE RESULTS OF FIELD EXPERIMENTS FOR 1915

Only the figures for alfalfa and soy beans at Marshfield could be obtained at this time. The general plan of the field work differed somewhat from that in the pot experiments. For each species of legume sixteen plots were used. These were arranged as follows: control, one ton of limestone, three tons, and eight tons respectively. In each test duplicate plots, inoculated and uninoculated were made.

The influence of treatment on alfalfa and soy beans is well illustrated in the follow-

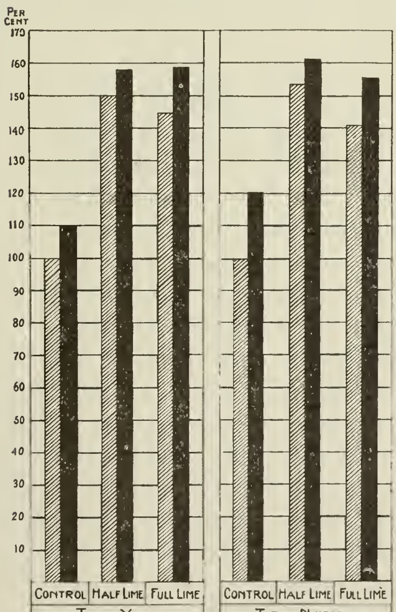

FIG. 13.—GROWTH AND NITROGEN FIXATION OF CLOVER ON PLAINFIELD SAND

The checked columns denote uninoculated and the dark columns inoculated.

ing diagrams. Figure 14 gives the total yield in pounds per acre. The complete tabular data will be given in an early report. In accord with the results of greenhouse work, inoculation or inoculation and lime greatly stimulated the growth and nitrogen content of alfalfa. The greatest difference in yield of dry matter and nitrogen between the inoculated and uninoculated series alfalfa was found in the no lime group. In other words, lime alone seemed to partly replace inoculation.

Concerning the amount of limestone to add, the data indicate that between one and three tons will give the most profitable returns. When applied in large quantities, eight tons per acre, there is a decrease in yield.

In general, soy beans responded to inoculation and lime in much the same way as alfalfa. Unfortunately one of the uninoculated control plots became infected with soy bean bacteria, thus causing a wide difference between the controls. With this exception, it will be seen that soy beans on Colby silt loam soil were greatly benefited by inoculation. Where both lime and inoculation were used there was a slight gain in yield and total nitrogen, but hardly enough to warrant recommending lime for soy beans. Liming alone did not cause any very consistent gain. Figures 15 shows the nitrogen content of alfalfa and soy beans.

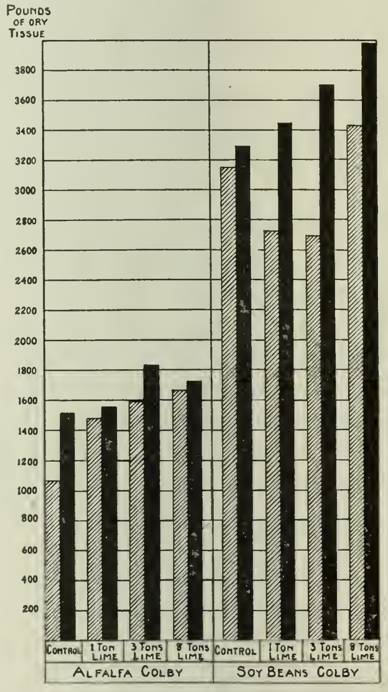

FIG. 14.—THE GROWTH OF ALFALFA AND SOY BEANS ON COLBY SILT LOAM

The checked columns denote uninoculated and the dark columns inoculated.

A review of the data of these two field tests indicates very strongly the beneficial effect of inoculation alone for soy beans, and for alfalfa inoculation and possibly a small application of limestone.

THE EFFECT OF TREATMENT ON THE NITROGEN BALANCE

In order to measure the gain or loss of nitrogen in cultivated soil planted to legumes, it is necessary to consider several factors: (1) the loss of nitrogen by leaching or denitrification; (2) the nitrogen removed by the crop; (3) the nitrogen added to the soil in seed, water, etc.; (4) the nitrogen present in the soil at beginning and at end. Since a study of this nature requires a relatively long period of time, one year or more, it is almost impossible to keep absolute control of all the factors. Moreover, the very best methods of drawing samples of soil and plant tissue, as well as methods of determining total nitrogen, are not accurate enough to detect slight changes in the nitrogen supply of the soil. The conditions of the previous experiments were carefully controlled. All the soils were kept in large glazed jars and protected from rain or dust. The moisture content was held at about half saturation. Nitrogen determinations were made of the soil, at the beginning and at the end as well as of the seed, and dry matter removed. Whenever roots were removed, they were analyzed and their nitrogen content added to that of the soil.

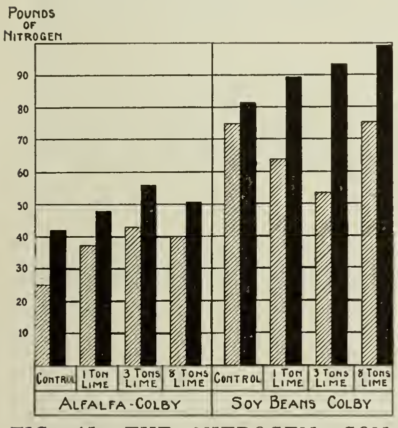

FIG. 15.—THE NITROGEN CONTENT OF ALFALFA AND SOY BEANS ON COLBY SILT LOAM

The checked columns denote uninoculated and the dark columns inoculated.

The balance of nitrogen for the five different experiments is shown in the data of Table XIII. From the figures of columns 1 and 2, it will be noted that in the majority of cases with alfalfa the nitrogen content of the soil was less at the end than at the beginning. Because of the large amount of tissue removed, this is not surprising. Apparently the amount of nitrogen fixed in the underground portions of the leguminous plants is not great enough to compensate for the loss due to the removal of the tops. In the case of clover,

TABLE XIII.—THE NITROGEN BALANCE IN ACID SOILS AFTER GROWING VARIOUS LEGUMES

Name of Crop	Soil	Treatment		Average total nitrogen in				Gain or loss in total nitrogen	Increase in total nitrogen due to treatment	
		Calcium carbonate per 100 gms. of soil	Inoculation	Soil at the beginning plus seeds	Soil at the end plus nitrogen in roots	Crops removed from soil	Soil plus crops at the end		Average amount for duplicate pot	Per acre
				1 Mgm.	2 Mgm.	3 Mgm.	4 Mgm.	5 Mgm.	6 Mgm.	7 Lbs.
Alfalfa	Colby silt loam	a.[1]	U[2]	30758.2	30576.5	1182.5	31759.0	1000.8		
			I	30758.2	30991.3	2059.7	33051.0	2292.8	1292.0	206.7
		b.	U	30758.2	30161.3	2444.8	32606.1	1847.9	847.1	135.5
			I	30758.2	30046.2	2640.9	32687.1	1928.9	928.1	148.5
		c.	U	30758.2	29638.7	2565.9	32204.6	1446.4	445.6	71.3
			I	30758.2	30166.1	2719.6	32885.7	2127.5	1126.7	180.3
Alfalfa	Plainfield sand	a.	U	13174.2	12770.0	463.0	13233.0	58.8		
			I	13174.2	12696.9	974.7	13671.6	497.4	438.6	70.2
		b.	U	13174.2	12519.0	2033.6	14552.6	1378.4	1319.6	211.1
			I	13174.2	13795.7	2171.0	15966.7	2792.5	2733.7	437.4
		c.	U	13174.2	13128.2	1888.3	15016.5	1842.3	1783.5	285.4
			I	13174.2	13110.0	2146.0	15256.0	2081.8	2023.0	323.7
Alfalfa and Soy beans	Colby silt loam	a.	U	30929.0	30358.7	2017.2	32375.9	1446.9		
			I	30929.0	30435.8	2354.2	32790.0	1861.0	414.1	66.3
		b.	U	30929.0	30413.0	1986.2	32399.2	1470.2	23.3	3.7
			I	30929.0	30869.9	2491.2	33361.1	2432.1	985.2	157.6
		c.	U	30929.0	30492.3	2033.4	32525.7	1596.7	149.8	23.9
			I	30929.0	30376.0	2790.9	33166.9	2237.9	791.0	126.5
Clover	Colby silt loam	a.	U	30757.5	31031.4	1998.2	33029.6	2272.1		
			I	30757.5	31028.7	2034.8	33063.5	2306.0	33.9	5.4
		b.	U	30757.5	30240.0	2279.4	32519.4	1761.9	−510.2	−81.6
			I	30757.5	31051.0	2246.8	33297.8	2540.3	268.2	42.9
		c.	U	30757.5	30755.0	2317.2	33072.2	2314.7	42.6	6.8
			I	30757.5	30545.0	2386.5	32931.5	2174.0	−98.1	−15.7
Clover	Plainfield sand	a.	U	13173.5	14444.0	1604.5	16048.5	2875.0		
			I	13173.5	15144.0	1945.7	17089.7	3916.2	1041.2	166.6
		b.	U	13173.5	14975.0	2473.9	17448.9	4275.4	1400.4	224.0
			I	13173.5	14776.0	2614.7	17390.7	4217.2	1342.2	214.7
		c.	U	13173.5	13415.0	2276.9	15691.9	2518.4	−357.6	−57.2
			I	13173.5	14876.0	2510.9	17386.9	4213.4	1338.4	214.1

[1] a represents no lime.
b represents one-half lime.
c represents full lime.

[2] I inoculated.
U uninoculated.

especially clover on Plainfield sand, no decrease was noted in nitrogen content of the soil. The results of the table bring out very sharply the large and uniform gain in nitrogen in the treated series. In columns 6 and 7 the increase in total nitrogen due to treatment is recorded in milligrams and pounds per acre. The figures represent the average differences between the controls and the treated series. From the data in these columns, it is apparent that when the soil is treated with lime, properly inoculated legumes alfalfa especially, fix large quantities of atmospheric nitrogen. The gain in nitrogen due to treatment was greatest with alfalfa on Plainfield sand. In terms of pounds per acre, the maximum gain for the five crops of alfalfa in sand was 437.4 pounds and for Colby silt loam, 206.7 pounds. It is significant that inoculation caused an increase in nitrogen in all of the different crops. Only three variations were noted—in the case of clover on Colby silt loam and clover on Plainfield sand a loss of nitrogen was found. In view of the marked effect of a very slight error in analysis, it is not surprising that there should be occasional variations. In a soil on which clover has been grown for many years, it is very probable that treatment will have very little effect. The data of Table XIII are in accord with this statement. Clover inoculated or limed did not give any very great increase for treatment.

A study of the data brings out many points of interest. The gain in nitrogen, aside from that in the tops of the legumes, may be accounted for in many ways: (1) absorption of nitrogen fixed in the roots of legumes; (2) free nitrogen fixation; (3) the addition of small amounts of ammonia nitrogen in the distilled water.

A determination of the beneficial effect of treatment, by subtracting the uninoculated from the inoculated, does not give fair results since in almost every case the legumes were partly inoculated. While the figures in columns 6 and 7 of Table XIII represent the effect of treatment, it would not be correct to consider these as the only gain due to treatment. Apparently the actual quantity of nitrogen taken from the air was far in excess of the figures shown in these columns.

SOURCE OF NITROGEN

Because of the methods followed, namely, soil unsterilized and crops grown under conditions which did not entirely

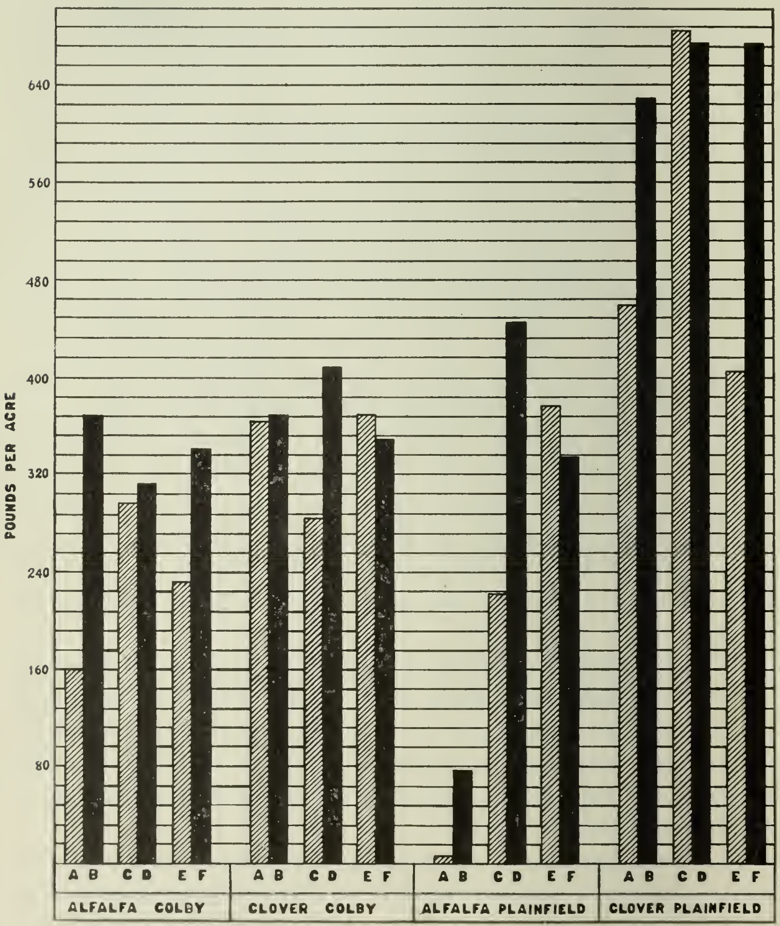

FIG. 16.—THE NITROGEN GAIN AFTER GROWING VARIOUS LEGUMES

AB. Control; CD. half lime; EF. full lime. The checked columns denote uninoculated and the dark columns inoculated.

prevent contamination, all of the jars were partly inoculated. In some cases, natural inoculation was far greater than in others. Apparently inoculation depends to a great degree on the species of plant as well as the soil type. As a rule, the

Colby silt loam soil showed a far greater natural inoculation than Plainfield sand. Likewise, clover showed a far greater natural inoculation than alfalfa.

In spite of the fact that the controls were already partly inoculated, the data of Table XIII were arranged to illustrate the amount of nitrogen gained due to the various treatments. The results are presented in Figure 16.

The pronounced effect of treatment on the source of nitrogen is very clear from the columns of the figure. Under good conditions, alfalfa and clover apparently will take by far the greater parts of their nitrogen from the air.

SUMMARY

The results of greenhouse studies with various soils and various leguminous plants show a very striking increase in plant growth and nitrogen content from inoculation. The addition of lime in large or small quantities exerted a beneficial effect on certain plants. In general, half enough lime to neutralize soil acidity is sufficient for the production of a good crop.

In the experiments of 1914 it was found that the growth and nitrogen content of alfalfa plants on Colby silt loam soil are greatly increased by inoculation. This influence was most noticeable in the limed series. The benefit of lime alone was much less pronounced than inoculation alone.

In the case of soy beans in the same soil, inoculation caused a very marked increase in both yield and quantity of nitrogen. Lime apparently did not have any decided influence on soy beans.

In the experiments of 1915, Colby silt loam series, the increase in growth and percentage of nitrogen in inoculated alfalfa far exceeded that of the previous year. In this test five cuttings of alfalfa were secured. The marked response of the alfalfa to inoculation is shown in each cutting. The increase in yield, as compared with the control, became more apparent with each crop. The jars which received both lime and inoculation gave the greatest yield of dry matter. Here again, one-half and full lime failed to produce any decided difference. Applications of lime alone gave a gain in plant growth. The highest percentage of nitrogen usually occured in the smallest crops or vice versa.

In the Plainfield sand an enormous increase was noted wherever the proper bacteria were added. At first this treatment did not increase the yield. After the second cutting, however, the plants in the inoculated jars far exceeded those of the controls. From the data it is very clear that applications of legume bacteria are even more beneficial to the growth of alfalfa on Plainfield sand than on Colby silt loam. The statements previously applied to lime on Colby soil also apply to Plainfield sand.

A repetition of the previous experiments, using clover on the two soil types, gave different results. Neither inoculation nor lime showed any decided influence on the growth or percentage of nitrogen in clover grown on Colby silt loam. A slight increase followed liming.

Clover on Plainfield sand responded to treatment. Inoculation alone caused an increase in crop yield and in total nitrogen. As compared with the controls, lime greatly favored the growth of clover. Lime and inoculation gave the maximum yield of dry matter and the maximum amount of nitrogen. It was found, as expected, from the results of the alfalfa experiments, that one-half enough lime to neutralize soil acidity was most beneficial to crop growth.

The results obtained from field experiments with alfalfa and soy beans on Colby silt loam soil agree in general with those of the pot tests.

A general review of all the data brings out two fundamental facts: (1) The characteristic effect of inoculation of alfalfa on Colby silt loam and Plainfield sand is an increase in plant growth accompanied by an increase in fixation of atmospheric nitrogen; (2) small applications of calcium carbonate on acid soils are far more economical than large applications.

PLATE I.—EFFECT OF TREATMENT ON THE FIRST CROP OF ALFALFA ON PLAINFIELD SAND

Jars 1 and 2 uninoculated; jars 3 and 4 inoculated plus half lime; jars 5 and 6 inoculated plus full lime.

PLATE II.—EFFECT OF INOCULATION ON THE FIFTH CROP OF ALFALFA ON PLAINFIELD SAND WITHOUT LIME

The jar on the left uninoculated, the jar on the right inoculated with a culture of alfalfa bacteria.

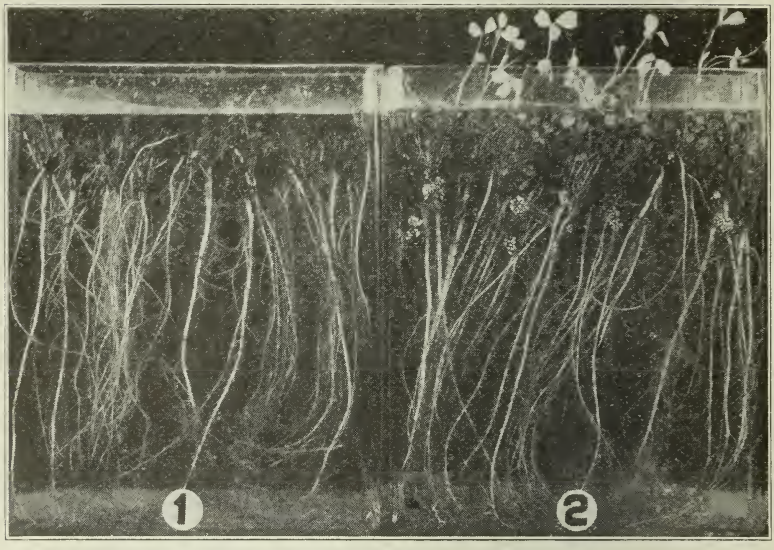

PLATE III.—EFFECT OF INOCULATION ON THE ROOTS OF ALFALFA IN PLAINFIELD SAND WITHOUT LIME

The roots (1) from uninoculated alfalfa; the roots (2) from inoculated alfalfa.

PLATE IV.—EFFECT OF TREATMENT ON THE FIRST CROP OF RED CLOVER ON PLAINFIELD SAND

Jars 1 and 2 uninoculated; jars 3 and 4 inoculated plus half lime; jars 5 and 6 inoculated plus full lime.

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Some Economic Factors Which Influence Rural Education in Wisconsin

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MADISON, WISCONSIN

CONTENTS

Some Economic Factors Which Influence Rural Education in Wisconsin

Summary

This study shows that:—

I. The average size of farms in the developed portion of Wisconsin is gradually increasing.

II. The average size of the farm family is gradually decreasing.

III. The average enrollment in the one room rural school is consequently decreasing.

IV. The rural school of less than 20 pupils is economically inefficient on account of high cost per pupil.

V. Aside from the one room rural schools, state graded and high schools can most economically and most completely meet the needs of rural education.

Conclusions

I. Under present economic tendencies the country school district should contain at least six sections of land in compact form.

1. **Because** the average Wisconsin farm contains about 120 acres.
2. **Because** the average number of children per farm between 6 and 14 years of age is but one.

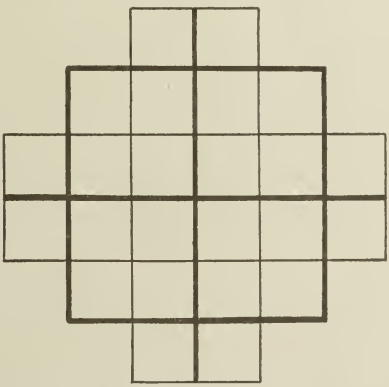

FIG. 1.—A POSSIBLE IDEAL*

Why not a school district of this size and shape, composed of four sections and four half-sections of land?

3. **Because** a district of six square miles area contains but 32 farms of average size and hence but little more than 30 pupils likely to attend school.

II. The further reduction in area of rural school districts below 3840 acres should be prohibited.

* This unit, which in many cases will prove impracticable, may well serve as the ideal in the reorganization of districts in a considerable portion of the state, particularly in the northern section.

III. Under ideal conditions of roads and topography the rural school district should be of the shape indicated.

1. Because such a district contains six sections of land in the most compact form.
2. Because with the school house located at the center, the most remote portions of the district are within two miles from school.

IV. The opportunity of state graded and high schools, better to serve the cause of rural education, lies in providing adequate transportation facilities and in adapting their curricula to the needs of country life. Such courses of study necessarily include agriculture and domestic economy.

PART I.—RELATIONSHIPS BETWEEN RURAL ECONOMICS AND EDUCATION

Eugene Merritt and K. L. Hatch

While it is unquestionably true that rural schools are limited in scope and controlled and directed in activity by the economic forces operative in the country, no graphic picture of these conditions has yet been presented.

This bulletin attempts to disclose some of these relationships. Emphasis has been placed on the following factors:

I.—The rise in land values,
II.—Changes in the size of farms,
III.—The movement of rural population,
IV.—Changes in the size of farm families,
V.—Changes in the composition of rural population,
VI.—Changes in land tenure, with their resultant effects upon the quality and kind of rural education.

While economic factors have received primary consideration the influence of so-called "social forces" has not been ignored.

It is believed that a knowledge of the above factors is necessary to the highest future development of rural schools.

Field studies in Iowa and Walworth counties, the questionnaire method, publications of the Bureau of Census, the original returns of the census enumerators, and the reports on file in the office of the State Superintendent of Public Instruction were used as material for this study.

The Decline in Rural Population

In recent years considerable anxiety has been expressed because of the decrease in the rural population in certain parts of the United States. This decrease has been most noticeable in the North Atlantic and North Central states, that is, in sections where the land values are comparatively high. Decreasing rural population and rising land values seem to be associated, as shown by the accompanying maps. If a further examination be made, it is found that in practically the same areas there has been a decrease in the total number of farms.

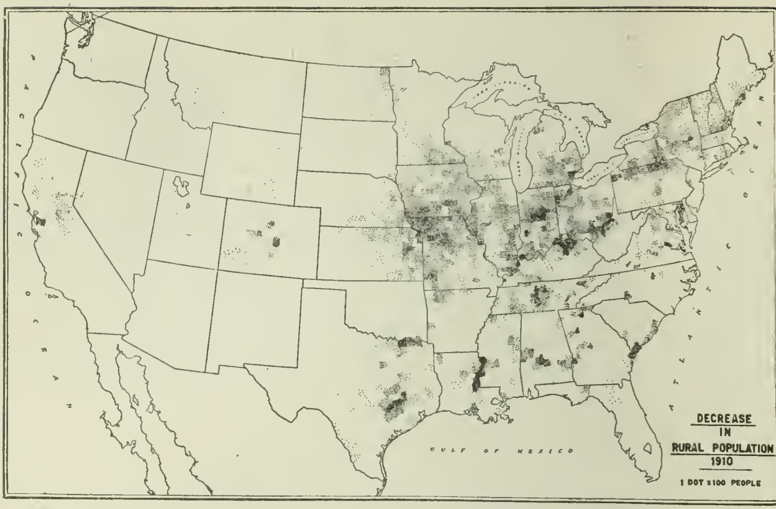

FIG. 2.—DECREASE IN RURAL POPULATION

Regions where rural population is on the rapid decline are shown by numerous dots. Note association with high land values.

If one examines into the conditions surrounding agriculture and the movement of rural population in Wisconsin, as revealed by returns to the Bureau of Census, it may be possible to find an explanation for these phenomena.

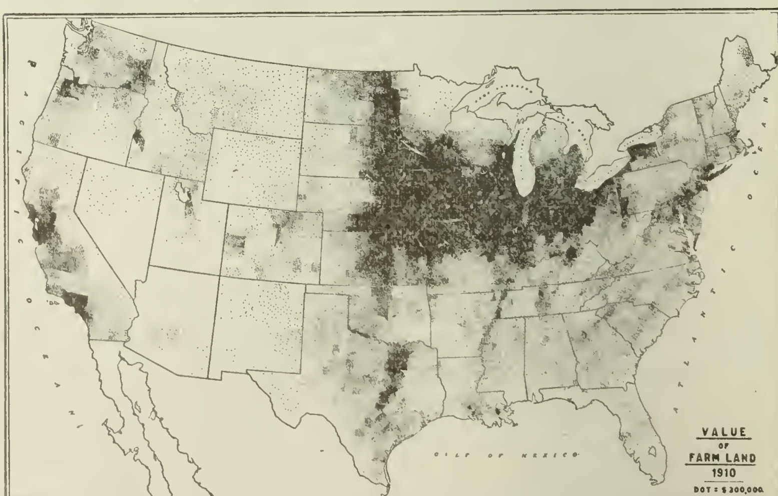

FIG. 3.—REGIONS OF HIGH LAND VALUES

Regions where land values are high are shown by numerous dots. In this same area tenantry is on the increase.

LAND IN FARMS

It must be borne in mind that the southern portion of the state of Wisconsin was developed much earlier than the northern portion. Indeed, many of the northern counties have at present but a small percentage of the total land

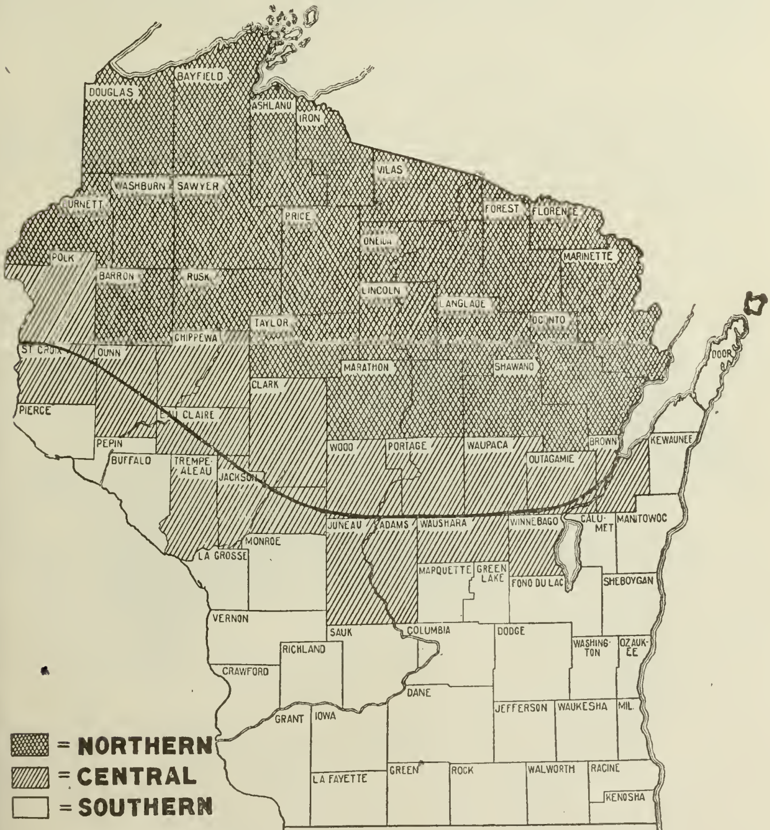

FIG. 4.—WISCONSIN'S AGRICULTURE BUT PARTIALLY DEVELOPED

This map shows three well defined areas in Wisconsin which are made the basis of several distinct classifications, used in this publication.

area in farms. If a line is drawn across the state from the southern portion of Polk county, swinging south to Juneau and Adams and north again to Brown, thus dividing the state into two portions, all the counties to the south of this line will be found to have more than 80 per cent of their land in farms. In most of the territory north of this line less than 50 per cent of the land is in farms.

Since it is necessary to make frequent reference to the above areas, that portion of the state to the north of this division line has been briefly designated the northern section and that lying south of it the southern section. Those counties immediately bordering on this line constitute another belt which will hereafter be referred to as the central section.

IMPROVED LAND IN FARMS

In the southern section the greater portion of the land in farms is improved, whereas in the northern section but a small percentage of the land in farms is improved.

FIG. 5.—WHERE FARMS ARE FEW IN NUMBER

The agriculture in the shaded area is comparatively undeveloped. Only a small percentage of the land (3% to 40%) is in farms, hence they are relatively few in number and more or less widely scattered. (Census 1910).

AVERAGE SIZE OF FARMS

By noting sizes of farms in different regions and using the total land area as a basis, one finds that no one type predominates in any particular region, except that in a general way the counties in the western half of the southern section have larger farms than those in the eastern half of

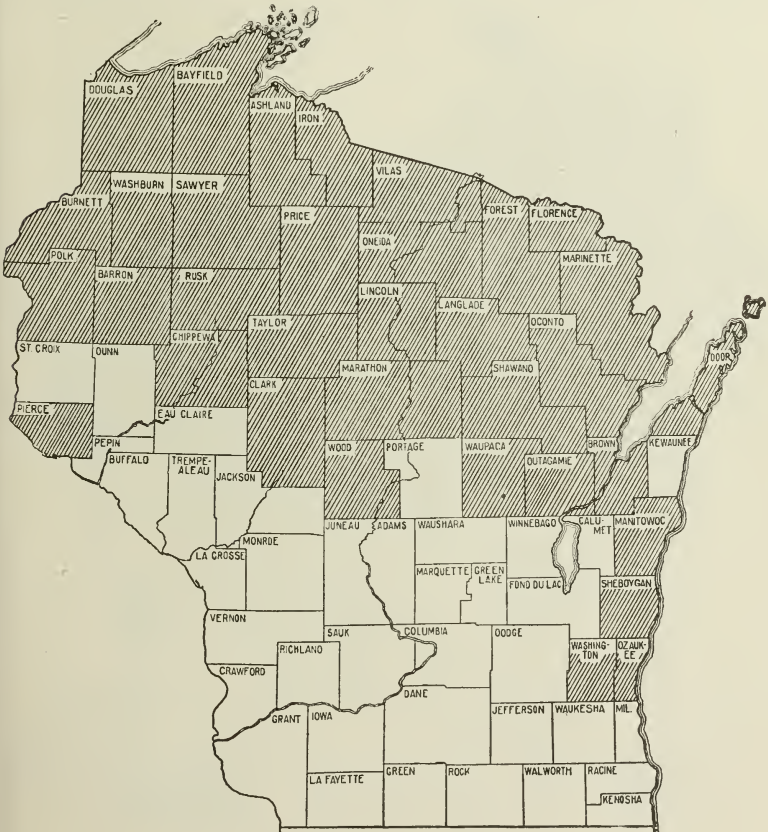

FIG. 6.—WHERE FARMS ARE RELATIVELY SMALL

In over half of the state the cultivated area per farm is relatively small. In the shaded counties, this averages less than 65 acres per farm; much less in the extreme northern section. (Census 1910).

this same area. Using the average acreage of improved land per farm as a basis, the counties of the northern section are found to have less than 50 acres of improved land per farm, whereas the counties of the southern section have on the average more than 80 acres of improved land per farm.

CHANGES IN NUMBER AND SIZE OF FARMS

Increase and decrease in number of farms are confined to definite areas. The number of farms in 1910 had increased over the number in 1900 in practically all of the counties in the northern section, while in the southern section the number of farms had decreased. In this southern section,

FIG. 7.—INCREASE CONFINED PRINCIPALLY TO NORTHERN COUNTIES

The disappearance of many of the smaller sized farms throughout the southern section of the state from 1900 to 1910 has had the effect of decreasing the total number of farms in this same area. Only shaded counties show an increase.

farms of from 10 to 19 acres had increased in number in both decades, between 1890 and 1900, and between 1900 and 1910; yet the farms of from 20 to 49 acres had decreased in all counties in this area. Between 1890 and 1900, this

line of division was farther south, yet there was, even at that time, a large number of southern counties in which farms of 20 to 49 acres had decreased in number. Farms of 50 to 99 acres showed a similar tendency in the southern area. The number of farms of between 100 and 174 acres decreased in only a few localities. One of these areas com-

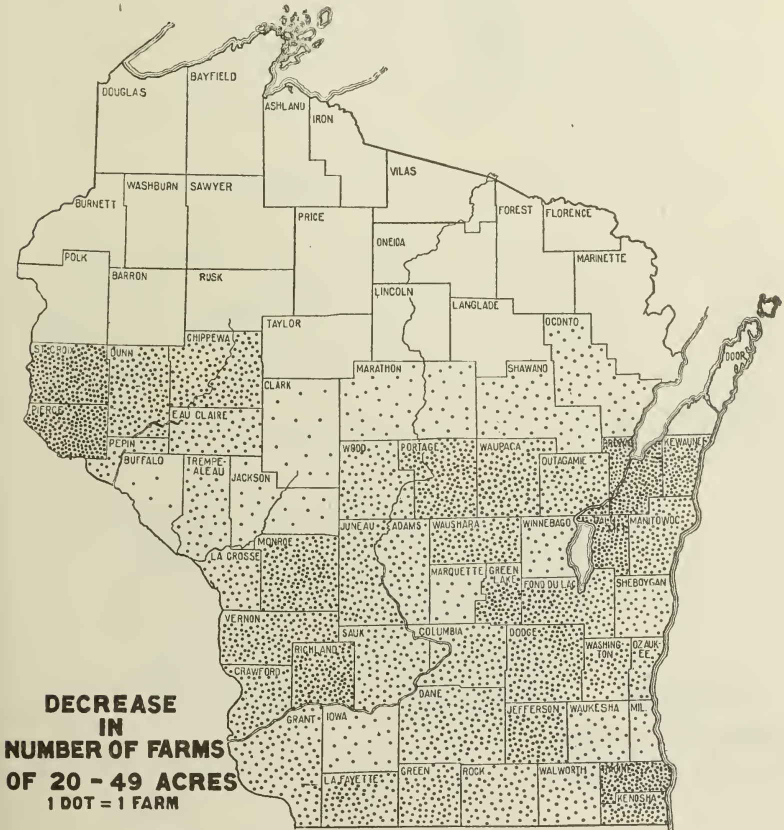

FIG. 8.—THE SMALL FARM UNPOPULAR

The "forty acre farm" is popular with the pioneer but such farms rapidly disappear as agricultural conditions improve. (Census 1900–1910).

prised the counties of Buffalo, Trempealeau, Jackson and La Crosse; another, Juneau, Adams, Marquette and Green; and a third, Crawford, Grant, Iowa and La Fayette. For the remainder of the state, farms of this type have increased in numbers in the last 10 years.

As the size increases above 175 acres, the number of farms in each class appears to be decreasing. Farms of between 175 and 259 acres seem to be decreasing, however, in an entirely different region from those of the smaller groups. This region consists principally of the counties bordering on or near the lake.

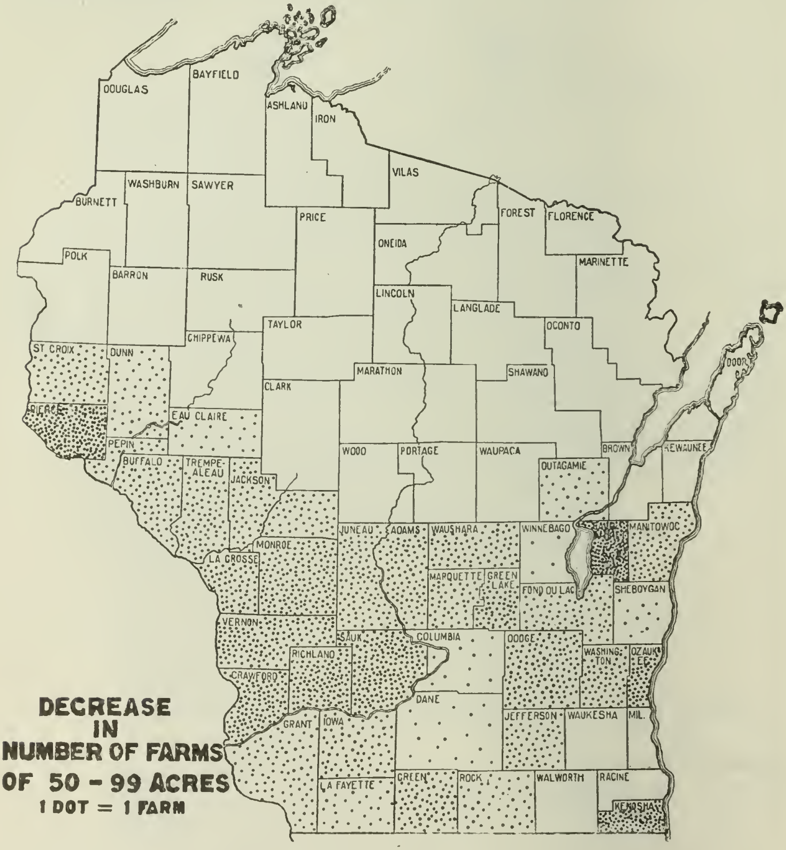

FIG. 9.—THE EIGHTY ACRE FARM GOING OUT OF FASHION

With the further advance in agriculture the "eighty acre farm" has followed the "forty" as shown by the above map based on the census of 1910.

Farms of between 260 and 499 acres decreased in the areas mentioned above and in the counties bordering directly on them. Farms of over 500 acres have decreased in number in all counties of the southern section.

The highest percentage of farms of between 20 and 99 acres is located in the northern section, or more recently

settled portions of the state, while the smaller percentages of farms of this size are found in those counties which were settled first. In 1880 (the first year in which the census noted size of farms) the largest number of farms of this size was found in the southern counties. With each succeeding decade this type of farm has moved gradually northward until it is now found in greatest proportionate numbers in the counties in the extreme northern portion of the state.

Another peculiar fact to be noted from the census of 1910 is that the number of farms of 10 to 19 acres has increased throughout the entire state.

Are We Developing a Land Monopoly?

It seems that farms of between 20 and 99 acres are being eliminated in southern Wisconsin. If this indicated a land monopoly the result would be that farms of more than 500 acres would be increasing, but as a matter of fact this type also declined in practically all counties of the state in the last census decade, and in many counties farms of 260 to 499 acres also decreased in numbers. In these southern counties the number of very small farms has increased. Several of the counties in which the total number of farms has decreased show an increase both in total farm land and in improved land. The tendency seems to be to increase the number of very small and medium-sized farms at the expense of many comparatively small and a few very large farms, with the result that in the older settled counties the total number of farms has decreased.

Similar tendencies in Iowa, Illinois and Indiana have been observed by others.

Rural Population

In Wisconsin in 1890 there were four persons living in rural districts to two in urban, but in 1910 there were four living in rural districts to three in urban. The increase in rural population between 1890 and 1900 was 1.3 per cent, and between 1900 and 1910, 5.7 per cent while that in urban was 40.6 per cent and 27.1 per cent respectively for the same periods. The increase in rural population for the state as a

whole is largely due to the rapid settlement of the northern section, as the accompanying map will show.

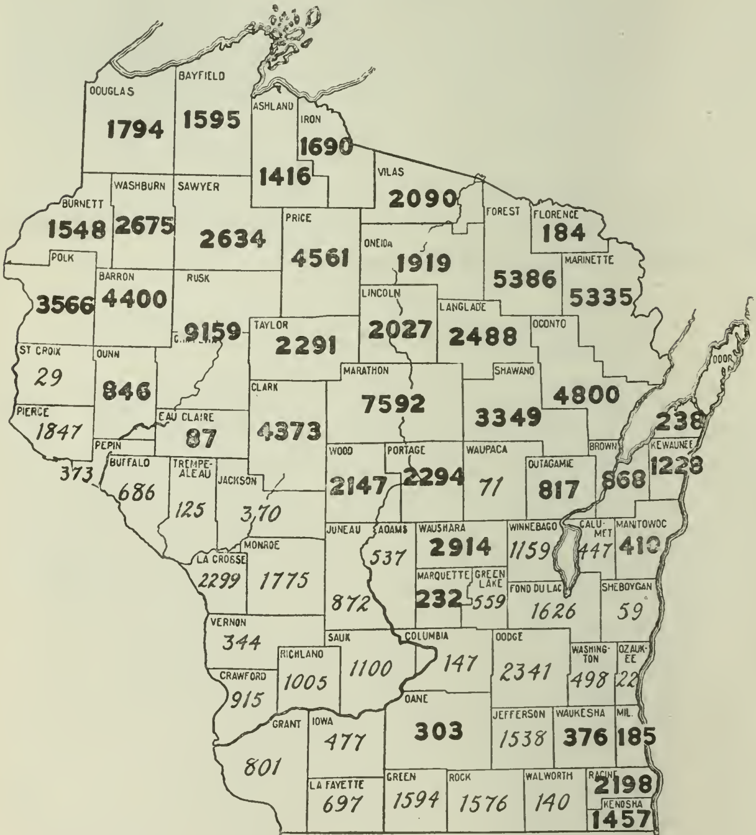

FIG. 10.—HOW RURAL POPULATION IS CHANGING

This map shows the actual increase or decrease in rural population in Wisconsin between 1900 and 1910 by counties. Cities and villages of less than one thousand population are counted as rural. Light face type shows decrease, bold face, increase.

Native Stock Increasing

Analyzing the rural population as to place of birth, we find that the number of those foreign-born had actually decreased between 1890 and 1910, whereas those of mixed or foreign parentage but native born had increased slightly over 20 per cent, the increase for the last 10 years being very small. The largest percentage of increase, however, was in those of native parentage; between 1890 and 1900

the increase was about 26 per cent, and between 1890 and 1910, 53 per cent. Thus we see that foreign immigrants are not now coming into the rural districts in such great numbers as they formerly did, and that the percentage of native born rural population is rapidly increasing.

EXCESS OF MALES IN RURAL DISTRICTS

If we examine the statistics showing the proportion of males to females, we find that there is an excess of males in the state, and that this excess was larger in 1910 than in 1900.

The excess of males in 1910 was:

8,500 in urban districts, and
74,800 in rural districts.

When the native whites are considered by themselves we find that there are:

24,200 more females than males in urban districts, but
38,500 less females than males in rural districts,

or in other words, there are more native women in proportion to men in cities than in the country. For the foreign born, the excess of males is larger in the country than in the city. It would seem, therefore, that the girls are leaving the rural districts faster than are the boys.

BOYS AND GIRLS LEAVING RURAL DISTRICTS

Migration by age groups:—If one analyzes the population by age groups, it is found:

1.—That for each age group there are more males than females living in rural districts.

2.—The next striking fact is that there is a higher percentage of children living in rural districts between 5 and 9 years of age than under 5 years of age.

3.—The proportion of both males and females living in rural districts decreases until the minimum is reached for both sexes in the ages of 25 and 34.

4.—In the age groups following this, the percentage living in rural districts begins to increase, the largest percentage for any age occurring in the group of 65 years or over. The same facts are true for both males and females except that the percentage for the females decreases more rapidly than that for the males.

The probable explanations for these variations are:

1.—The death rate among children is greater in the city than in the rural districts, so that an increased percentage survives in the country. This accounts for the increase in the second groups, 5 to 9 years.

2.—Beginning with the age group 10 to 14 years, the children, for various reasons, migrate to cities and this migration continues until the ages of 25 to 34 are reached.

3.—At 35 years of age the migration from rural districts practically ceases. The higher death rate, age for age, in the urban than in the rural districts accounts for the fact that a larger percentage of those in rural districts survive. That there is a return migration is also probable, particularly in the case of women between 20 and 30 years of age.

THE APPARENT REASON FOR THIS MIGRATION

Why should there be migration from the rural to the urban districts? Apparently it is simply a readjustment of the labor supply. In the first place the birth rate in the rural districts for persons of the same nativity is higher than that in the urban districts. For this reason, the labor supply of the country increases faster than it does in the city. On account of numerous changes in our systems of agriculture less labor is required to produce the same amount of crops; consequently at certain times of the year the rural districts have an excess of labor. Industries, giving continuous profitable employment to labor in the cities, are increasing so rapidly that the city is not only dependent upon the country for its food supply, but also, for men and women to carry on its increasing activities. The excess of labor in the rural districts migrates to the city to find employment. The desire of young people to find employment in cities should not be aroused by a system of education which exalts city life at the expense of the country.

CHANGES IN THE COMPOSITION OF RURAL POPULATION

The changes in rural population in Wisconsin are very significant. There has been a marked decrease in the number of foreign born. The average size of the families of the foreign born parents is larger than that of the native born parents. Hence the decrease in the number of foreign born in the rural districts tends to decrease the size of the family and the number of children that need schools. The effect of this change upon the community social life is also very

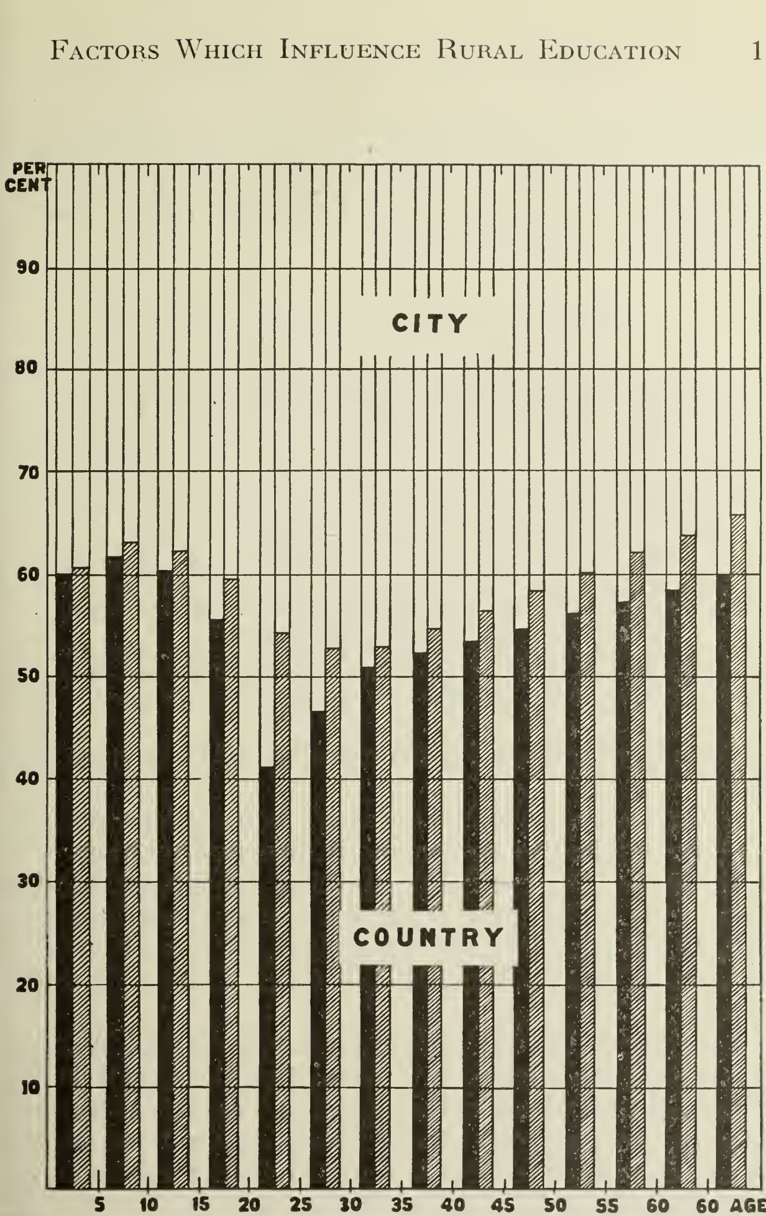

FIG. 11.—THE CITY CLAIMS MEN AND WOMEN IN THEIR PRIME

Solid black lines represent females; shaded lines, males. The chart shows distribution of population in Wisconsin by age groups, between city and country. Marriage apparently influences this distribution very materially among women.

important but will not be discussed here. As population increases, land values rise and it becomes more difficult for the immigrant to get possession of a farm. We may expect, therefore, that the number of foreign born in the rural communities will continue to decline.

SOME IMPORTANT RESULTS OF RURAL MIGRATION

1.—As soon as the boys become old enough to earn an independent living wage, some of them leave the home farm to go to the city. Many of them, however, find employment, either on the home farm or on some other farm, and remain as laborers in the country.

2.—On the other hand, very few girls become wage earners in rural communities. In recent years, many urban occupations have been opened to girls and they are migrating to the city to earn an independent living until they marry.

3.—There are many young men, foreigners, employed on the farms as laborers. They work on the farm long enough to learn the best farm practices here and perhaps to accumulate capital with which to begin independent farm operations.

4.—Most farm laborers, whether native or foreign born, are unmarried and remain so until they become independent farm operators or become established in some other occupation.

These facts account for the excess of males in rural districts.

As the amount of capital necessary to begin farming, and the time required to accumulate it increases, marriage will be delayed. The possibility of being self-supporting also causes girls to be more independent about marriage and tends to postpone the time of marriage. The result of later marriage is smaller families and fewer children in rural schools.

It is evident that if the size of the family declines, in order to maintain the present rural population there must be an increase in the number of farm families. As long as we continue the present order of one family on one farm, an increased number of families in a settled district will require a subdivision of farms. An alternative method of increasing the number of families is the employment of a larger number of married laborers on the farms.

TABLE I.—PER CENT OF TOTAL POPULATION OF SAME AGE AND SEX LIVING IN RURAL DISTRICTS: CENSUS 1910

Age period	Total		Native white		Foreign-born white	
	Male	Female	Male	Female	Male	Female
Under 5 years	60.6	60.2	60.7	60.3	34.1	37.0
5 to 9 years	62.5	61.7	63.2	62.3	35.0	36.2
10 to 14 years	61.9	60.7	62.4	61.2	43.4	41.6
15 to 19 years	59.7	55.5	61.0	56.4	40.8	36.6
20 to 24 years	54.0	40.6	57.7	51.6	36.9	33.2
25 to 34 years	51.4	50.2	56.4	52.8	38.7	40.6
35 to 44 years	54.9	52.8	59.4	54.9	47.1	47.9
45 to 64 years	59.2	55.3	62.0	55.8	56.4	54.4
65 years and over	65.6	59.4	67.2	59.0	64.8	59.3
All ages	58.1	55.8	60.4	57.1	50.3	49.6

We have noted that in the southern section there has been a decrease in the number of farms. But how long may we expect this tendency to continue? Certainly not indefinitely. If we turn to Europe for a suggestion as to the future, we are led to contemplate the possibility of a subdivision of farms and consequently an increase in number. The possibility of changes in types of farming and in farm organization makes any definite prediction impossible.

Suppose we have reached the point where the number of farms is to remain stationary? In the case of each family there is the one farm for one son and a daughter of another farmer say, or vice versa, hence other children must go elsewhere or become farm laborers. By increasing the intensity of culture more laborers are employed on the farms. Any increase in rural population beyond what is necessary to meet the farm demand is a surplus labor supply for the industrial centers. Or shall we suppose there is to be a subdivision of holdings? More children will find permanent employment on farms and the city migration will be reduced correspondingly.

However, in all parts of the United States and in all countries as far back as there is definite information, there has been a constant flow of people from the rural districts to the cities so that whatever change may take place in the type of farming or of the farm family, it is safe to assume that the movement of the people from the rural districts will continue in the future as in the past.

In any event, it will be the problem of the rural school of the future, as it is at present, to furnish the primary education for both those who are to remain in the rural communities and those who are to go to the city.

THE RELATION BETWEEN RURAL POPULATION AND THE NUMBER OF FARMS

All counties of the northern section of the state show an increase in rural population, whereas nearly all the counties of the southern section show a decrease. If cities and villages of less than 2500 are excluded from the rural population, the

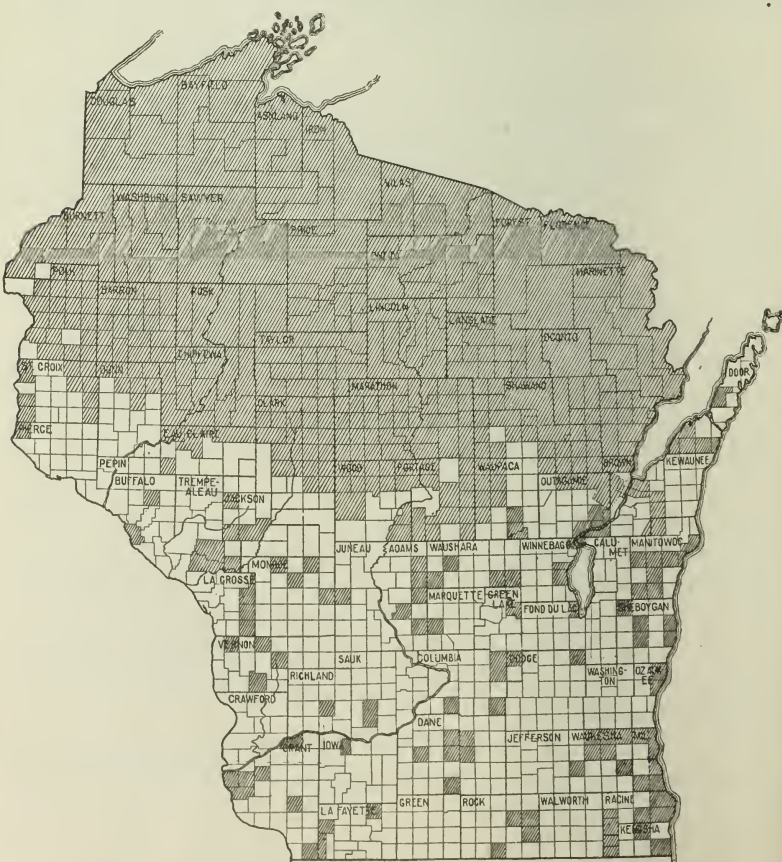

FIG. 12.—WHERE RURAL POPULATION IS INCREASING

Only those townships having an increase in rural population during the period of 1900 to 1910 are shaded. All others show a decrease. In the southern section of the state practically all the increase is in the immediate vicinity of the larger towns.

only counties south of the dividing line previously mentioned, which show a slight increase are Racine, Kenosha, Marquette, Waushara, Dane, Milwaukee, Waukesha (See Fig. 10, p. 12) and Manitowoc. All the other counties of the southern section show a decrease in rural population. It will be observed that the counties showing a decrease in the total number of farms lie in this same area.

By comparing the increases and decreases in the number of farms with the increases and decreases in the rural population, one finds that there is no uniformity in their relationship. An increase in the number of farms is not necessarily accompanied by an increase in the total population, but a decrease in the number of farms is generally accompanied by a decrease in the rural population. In some instances, however, there was an actual increase in rural population and a decrease in the number of farms.

Land Tenure in Wisconsin

It is a striking coincidence that the line which divides the state with respect to population and size of farms also divides the state with respect to ownership. In the northern section are located the counties having 10 per cent or less of tenants, whereas those counties to the south have a higher percentage, the highest percentage occurring in the counties along the southern border. In the last mentioned area, ownership has been decreasing in all counties except Sheboygan, Rock, Racine, and Kenosha. The number of tenants is increasing in all the counties of the state, excepting

> Brown, Columbia, Dane, Door, Dunn, Fond du Lac, Juneau, Manitowoc, Outagamie, Pepin, Portage, Racine, Rock, Sheboygan, Washington, and Waukesha.

The Relation of Rural Education to Land Tenure

The support which the rural school receives depends in a large measure upon the ideals and economic conditions of its patrons. We should not expect an ever shifting population to have the same interest in a school as permanent residents. Permanency of residence is affected by the tenure of land.

Farms are held by tenants under two different conditions and these conditions affect the permanency of tenure.

1.—The tenant who is related to the owner and who will probably own the farm in course of time, or the one who has permanent interest in the community through long time tenure.

2.—The tenant who has no permanent interest in common with either the owner or the community.

The interest of the former in the schools is the same as that of a permanent resident or future property holder. The latter presents a more serious rural problem.

The data given for Iowa county, suggests that the number of tenants who are related to the owner of the farm which they operate may be very large. This data does not separate the number of tenants who are related to the owner through marriage from those who are not related. It seems probable, in most cases in which the tenant and the owner of the farm have the same name, that they are related, and that in many cases where the tenant has a different name, he is related through marriage. The table also shows that some* of the tenants have occupied their present holdings for ten years or over and are still operating them.

A customary long time tenure, together with the hope of purchasing a farm in the same community when sufficient capital has been accumulated, will tend to modify the effect of an otherwise shifting tenant population.

TABLE II.—NUMBER OF TENANTS IN IOWA COUNTY WHO HAVE OCCUPIED THE SAME FARM FOR A SPECIFIED NUMBER OF YEARS

Years of occupancy	Number of tenants with same name as owner	Number of tenants with different name
1 year	37	134
2 years	27	50
3 years	24	22
4 years	15	9
5 years	12	9
6 years	10	10
7 years	8	4
8 years	11	8
9 years	2	1
10 years and over	27	12
Total	173	259

*About 10 per cent

RURAL SCHOOLS

Much concern has been felt about the educational conditions in the small, one-room, rural school.

WHERE ARE THE SMALL SCHOOLS?

In Wisconsin there are three definite belts of schools with less than 15 pupils each,—one, with a large number of schools of this type extending across the southern portion

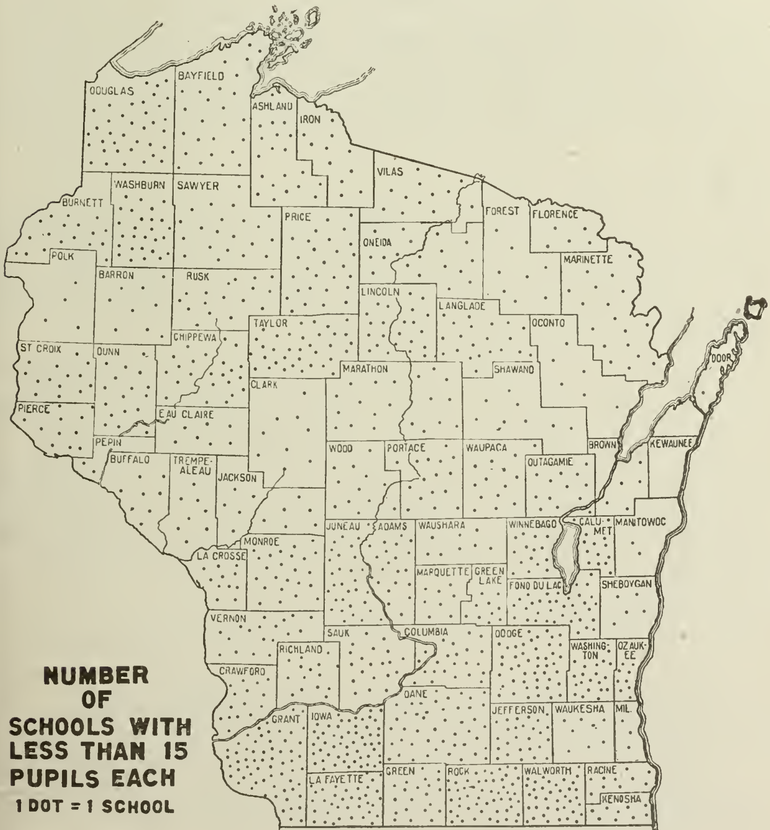

FIG. 13.—WHERE ARE THE SMALL SCHOOLS?

Small schools are found in two regions, where population is sparse, and, where rural population is on the decline.

of the state; another in the extreme northern portion of the state, with similar conditions; and an intervening belt showing a comparatively small number of schools of this type.

If we study the number of schools with less than 10 pupils each, the same condition is observed. But small schools are found in largest numbers in the earlier settled southern portion of the state.

WHAT ARE THE REASONS FOR THESE SMALL SCHOOLS?

There are several causes for this condition.

I.—In the northern portion of the state, as has already been pointed out, but a small percentage of the total land area is in farms; the farms are more or less widely scattered, with the result that within a definite school district there are but few families and, consequently, a small number of pupils.

II.—In the southern portion of the state, schools have been established, in many instances, when the number of persons of school age on farms was at its maximum. As the number of farms has decreased, the number of farm families has decreased accordingly.

III.—The composition of the population itself has changed. Many of the original settlers were of foreign birth. It has been shown that the number of children to the family to women of foreign birth is larger than the number of those of native parentage. Since the percentage of foreigners is decreasing and the percentage of natives is increasing, the number of children to the farm is necessarily decreasing.

A further analysis of statistics reveals that:—

1.—The largest families reside in the northern portion of the state.

2.—In practically all of these northern counties there is, on the average, more than one pupil to the family attending school.

3.—The counties having an average of five persons or more to the family, all lie in the northern portion of the state. The exact reason for this condition is not fully evident, but apparently it is due to the recent settlement of this section by a high percentage of foreign birth, and of comparatively young people whose children are still living at home.

In the southern section, even yet, school districts are being broken up into smaller units, with the result that we have more school districts, fewer families, and fewer children to the family than formerly.

SCHOOL ATTENDANCE

Rural and urban attendance compared.—The statistics of school attendance, as returned by the federal census, throw little light upon the present rural school conditions. The attendance of children of 6 to 14 years of age was better in urban than in rural districts, but the reverse was true for those of 15 to 20 years of age.

This first condition may be explained by the fact that many of the rural school children have so far to go over bad roads that they do not start to school at so early an age as do city school children. Statistics collected in Iowa county, and included in this study, show that 26.5 per cent of the children in that county of the age of six years were not in school.

It is also more difficult to enforce the compulsory attendance law in the country than it is in the city.

The higher percentage attendance of rural school children of 15 to 20 years of age may be explained as follows:

In the urban school the attendance at an early age is more regular and the grading of the pupil more exacting. The pupil is urged with greater force to keep step with his class through the eight grades to the end. After completing this work he must either go on to high school or drop out of school. There is, as a rule, plenty of opportunity for the city boy to earn wages during the winter, whereas the boy in the rural district has less chance for gainful employment. Hence the boy in the rural district who has passed through the eight grades of work may go to school a part of the year merely because he has nothing more immediately remunerative to do.

Foreign and native children compared.—When the statistics are further analyzed they show this rather peculiar fact:

1.—Children of all ages of foreign or mixed parentage attend school in relatively greater numbers in rural than in urban districts.

2.—Native white children attend school in relatively greater numbers in urban than in rural districts.

3.—But native white children attend in relatively greater numbers in both urban and rural districts than do those of foreign and mixed parentage.

ILLITERACY AS A TEST OF SCHOOL EFFICIENCY

Illiteracy has often been used as a test of the efficiency of an educational system, but a rather careful examination of the illiteracy figures indicates that it is more the result

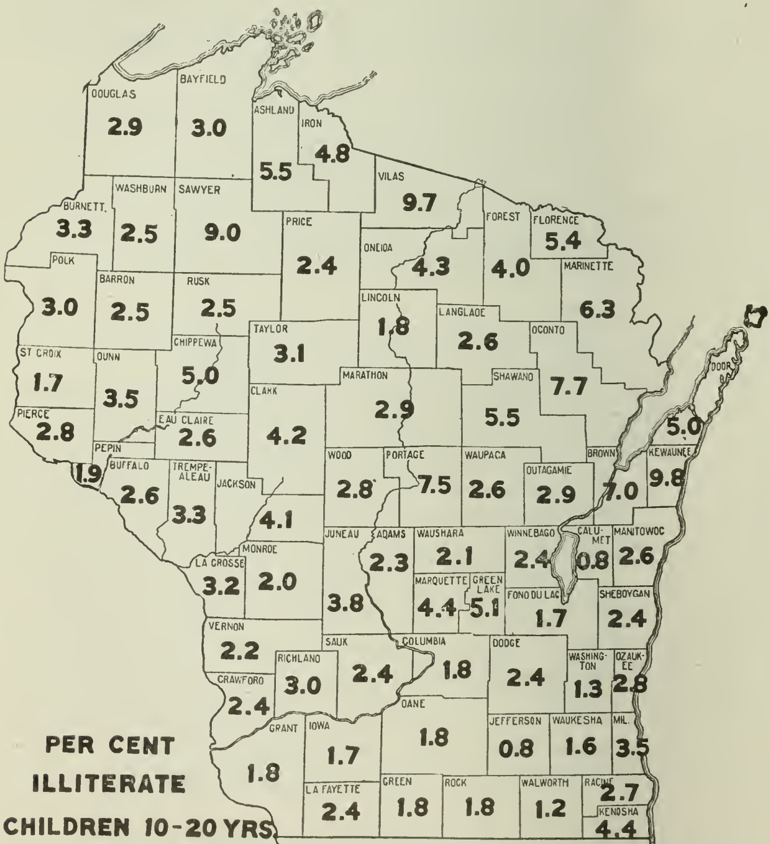

FIG. 14.—DISTRIBUTION OF ILLITERACY AMONG THE YOUNG

The highest percentage of illiterate rural school children is found in the newer sections of the state where population is sparse and of foreign birth or parentage. There is little if any difference between amount of illiteracy in urban and adjacent rural territory.

of social and economic conditions affecting parents than of the administration of schools.

Assuming, however, that the percentage of illiteracy among children from 10 to 20 years of age indicates a lack of school efficiency, we find that where a large number of schools

with small attendance are located, the percentage of illiteracy is the lowest in the state. Our conclusion must then be that the small school is efficient.

The Rural School Teacher

ARE OUR RURAL SCHOOL TEACHERS INADEQUATELY TRAINED?

The rural school teacher has been severely criticised for her lack of training. The report of the State Superintendent of Public Instruction shows that of the 6600 rural school teachers in Wisconsin:

2 per cent had only a common school education,
24 per cent had attended State Normal Schools,
26 per cent were graduates of County Training Schools,
44 per cent were graduates of high schools only.

Similar data for the state graded schools show that:—

52 per cent had attended State Normal Schools,
18 per cent were graduates of County Training Schools,
30 per cent were graduates of high schools only.

It seems, therefore, that the graded school teacher is somewhat better trained than the rural school teacher, but statistics indicate that as a class, rural school teachers in Wisconsin have had considerable training.

What is sufficient training for a rural school teacher? Standards will differ, but when this standard has been once determined the next question is, how may successful teachers with the desired training be secured and retained in rural schools?

THE RURAL TEACHERS' TENURE OF OFFICE

The rural school teacher has been much criticised because she does not remain longer in one particular school. The returns of 1913 show that the average teacher in the rural schools of Wisconsin has taught approximately three and one-half years and spent 55 per cent of that time in the school in which she was then teaching. A few teachers remain a long time in the service of country schools, but the returns show that they are continually changing from one school to another.

WHY DO TEACHERS NOT REMAIN IN RURAL SCHOOLS?

Some, for various reasons, quit teaching after a very short time.

Some continue teaching but soon advance into positions in graded or high schools.

The rural school is used in the latter case either as a training school or as a means of earning money to use in acquiring a higher education.

WHY DO THEY CHANGE FROM ONE SCHOOL TO ANOTHER?

Some change because of failure to "make good."

Some change for merely personal reasons for which the community is not at all responsible—for example to be nearer home, to be able to live with their relatives.

In many cases the change is made in order to get an increase in salary or better working conditions.

In some cases the districts are so small or the community so poor that only the minimum wage can be paid.

In other cases the people will not tax themselves to raise sufficient money or otherwise exert themselves to create desirable conditions for the school teacher, so that experience and efficiency must go elsewhere for remuneration.

Salary, of course, is an important item, but there are other things to be considered. Teachers may be willing to change from one school to another in the country or go into the graded schools at the same wages, because there is a more convenient and better place to board, better school buildings, better equipment and a more congenial community life.

PART II.—A STUDY OF IOWA COUNTY

Among the first settlements made in Wisconsin were those of Iowa county. This county is an agricultural district with no large or rapidly growing industrial centers. Its cultivated area has reached its maximum and its population is relatively stable. It has no large cities within its boundaries and is therefore particularly free from urban social and political influence. Though there are a number of lead and zinc mines within the county its chief industry is agriculture. It is therefore of particular interest as a typically rural Wisconsin county. Because it presents these conditions this county was selected for a more detailed study.

Basis for Comparison

The returns to the Census Bureau are made on two schedules: one showing the farm operations, the other showing the various factors relating to population. In this study an effort has been made to connect, so far as possible, the farm and the population schedules. In order to make comparisons possible the farmers were divided into groups of native and foreign born. These groups were further subdivided into tenants and owners, classified as to the number of years married and arranged according to size of farms. Only complete data have been used hence not all farms in Iowa county are included in Table III.

Table III.—Number of Families and Number of Children on Iowa County Farms.

	Tenants			Owners			Total		
	Number of families	Number of children	Average children per family	Number of families	Number of children	Average children per family	Number of families	Number of children	Average children per family
Native parents	314	861	2.7	1029	3903	3.8	1343	4764	3.5
Foreign parents	38	158	4.1	334	1963	5.8	372	2121	5.7
Total	352	1019	3.0	1363	5866	4.3	1715	6885	4.0
Married over 20 years	44	289	6.5	381	2050	5.3	425	2339	5.5

FAMILIES OF NATIVE AND FOREIGN BORN COMPARED

It appears that among the early settlers there were a great many foreigners, but that in recent years, few foreigners have been settling in this county. The younger generation of farmers is composed principally of natives and native born children of foreign parents.

Comparing the number of children to the family we find that the foreigners have larger families than the natives. Twenty-five per cent of the foreigners who have been married more than 20 years have 10 or more children to the family, whereas among the natives married the same number of years, but slightly over 10 per cent of the families have ten or more children. The average number of children to the family of those married over 20 years, for natives, is 5.5, whereas the number of foreign parents is 7. These facts agree with observations made with reference to the state as a whole, both as to the decrease in the number of foreign born and as to the smaller families of the native born.

THE RELATION BETWEEN TENURE, SIZE OF FAMILY AND SIZE OF FARM

An analysis of the relation of the size and tenure of farms to the size of the families on the farms reveals these facts:

1.—That usually the tenant farmer married the same number of years has a larger number of children than the owner farmer.

2.—The larger farms have the larger families.

3.—The average size of the farm operated by the tenant is larger than the average operated by the owner.

The relation noted between size of farm and size of family may, however, be only accidental, as those on the larger farms usually have been married the greater number of years. There is an interesting question suggested here in the fact that the average tenant family is larger than the average family of the owner operator married the same number of years. Are we developing a tenant class with large families and with necessarily low standards of living?

An analysis of statistics for this county shows that:

40 per cent of those married less than 10 years are tenants,
15 per cent of those married 10 to 20 years are tenants.

Thus we see that the number of tenants decreases rapidly with the number of years married.

When those owners with mortgages on their farms are separated from those holding their farms free and included in the comparison of those married 10 to 20 years we find that:

45 per cent are farmers with farms free,
40 per cent are farmers with mortgage on their farms,
15 per cent are tenants.

For those married more than 20 years:

57 per cent are farmers with farms free,
35 per cent are farmers with mortgages on their farms,
8 per cent are tenants.

Or by a different arrangement of the tenant data:

40 per cent of those married less than 10 years are tenants,
15 per cent of those married 10 to 20 years are tenants,
8 per cent of those married over 20 years are tenants.

These facts give evidence that there is a farm tenure ladder by which the young man rises from tenant to the ownership of the farm which he operates. The steps may be taken either by purchase by means of accumulated capital, or by credit, or both, or by inheritance.

We have noted that in Iowa county a large number of the tenants were probably related to the owner of the farm which they operated; that is, in many cases, the tenant is virtually a partner in business with his father. Such temporary tenants do not constitute a distinct economic class in the ordinary sense of the term. The increasing value of land may make progress from tenant to ownership by purchase more difficult but a more extensive use of credit will partially compensate for the rise in value. The number of tenants may increase but as long as they remain for a long term of years on the same farm and are taken from the present native population and for whom there is hope of becoming farm owners, they do not constitute a separate economic and social class to be considered separately when dealing with matters affecting rural education.

School Attendance in Iowa County

The data in regard to school attendance seem to be less accurate than the data for the other facts tabulated for

this county, therefore, too much dependence should not be placed on the results. These data show that:

I.—The school attendance of children 6 to 14 years of age was better for those of foreign parentage, but beyond this period the attendance was better for those of native parentage. Fifty per cent of the children 15 to 20 years of age remaining at home attended school.

2.—The children of tenants did not attend school in as large proportions as did the children of owners. This is true primarily because a larger proportion of the tenants' children are from six to seven years of age.

3.—It seems that the smaller the farm the smaller the attendance. This may be due to two factors: first, that the farmers on the smaller farms have a larger proportion of younger children; second, that these farmers require the labor of the children; whereas the farmers on the larger farms can afford to hire help.

SMALL SCHOOLS

In addition to the study of the census returns a field study of the county was made with the assistance of the county superintendent. This study shows that the most common size of the rural schools in this county is 15 pupils. There were many very small schools and but few have more than 30 pupils. This is the condition that exists in a rural county that for several years has had a practically stationary population. In fact, the rural population in this county has declined about 3 per cent in the past ten years, whereas the number of farms has increased slightly.

The small schools in this county seem to be, therefore, the result of causes that we have already observed to exist throughout the older settled portions of the state.

INFLUENCE OF HIGH SCHOOLS ON RURAL SCHOOL ATTENDANCE

A map of the rural schools of the county, indicating the number of pupils enrolled in each school, shows that the small schools are generally grouped around nearby high schools. If we turn to a map showing the distribution of high school attendance from rural districts, we see that there are a large number of high school students coming from these

same small districts. We must therefore conclude that the accessibility of high schools has a marked influence on the attendance from rural districts, and that the opportunity of securing a high school education is an incentive to the completion of the rural school course of study.

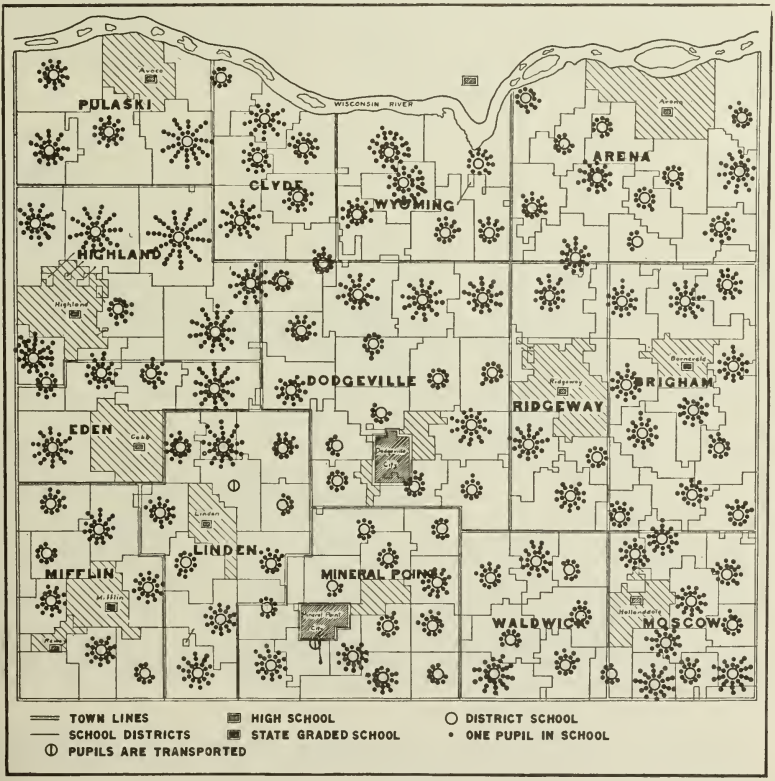

FIG. 15.—THE SIZE OF RURAL SCHOOLS

Map showing rural school attendance in Iowa county. Note that the small schools are located either in small districts or near the larger tonws of Dodgeville and Mineral Point.

One cause, therefore, of the small school may be its efficiency, measured, not by the number it can enroll on its records, but by the number that it can put through and send on to a higher school.

THE COST OF THE SMALL SCHOOL

So far, no reason has been revealed for condemning the small school; in fact there is no satisfactory method of meas-

uring the efficiency of any school. But the size of the school must be considered from the standpoint of financial support. The average salary of teachers in this county is but little over $40 a month. If she has only 10 pupils, the instruction cost per pupil was $4 a month; 20 pupils, $2 a month; 40 pupils, $1 a month. Other items in the cost of maintaining a school are comparatively small. On the average the maintenance cost is but little more for a school of 40 pupils than for one of 5 or more pupils.

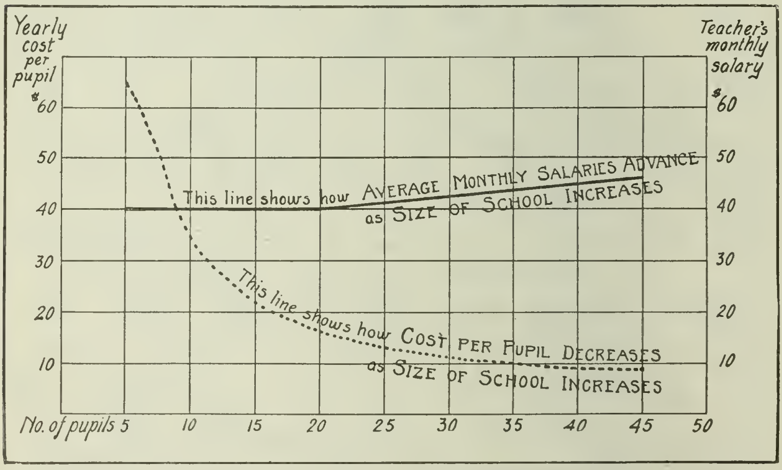

FIG. 16.—THE SMALL SCHOOL EXPENSIVE

Schools of less than 20 pupils each are seldom able to pay more than the minimum salary, hence they must employ the least efficient teachers. Even at this low rate of wages the average cost of instruction per pupil increases rapidly as the size of the school decreases.

The very small school from small districts and poor communities may be too great an economic burden to the patrons and result in the employment of inefficient teachers and the use of very poor equipment.

HIGH SCHOOLS FOR THE RURAL CHILDREN

Granting that a high school education is desirable for the boys and girls of rural communities, we find very good argument for placing high schools within easy reach of every farm so that the children may remain at home, at least over the week end. From a study of the map of high school attendance from rural districts in both Iowa and Walworth counties, it seems that:

1.—The better the transportation facilities to any high school center the greater the attendance.

2.—The attendance varies inversely with the distance from school.

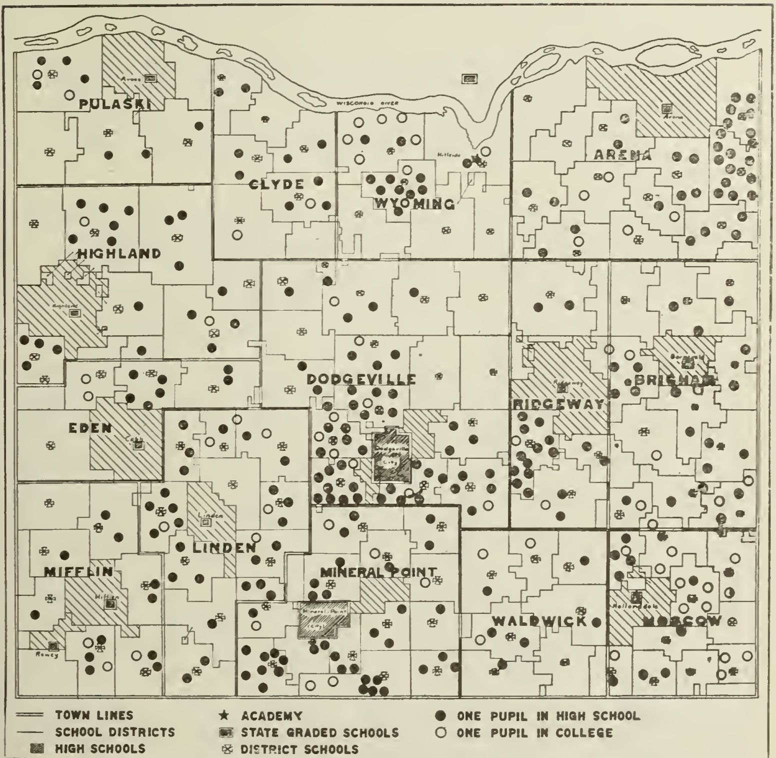

FIG. 17.—WHERE HIGH SCHOOL AND COLLEGE STUDENTS LIVE

Map showing high school and college attendance in Iowa county. There seems to be some association between the small school and attendance on high schools and colleges. Compare with map showing rural school attendance in Iowa county.

WHAT BECOMES OF THE FARM BOY AND GIRL?

Only a small percentage of the boys and girls of 15 to 20 years of age are in rural schools. A certain percentage of them are in high schools. Approximately 50 per cent of those remaining at home are in some type of school. But where are those that are not in school? Some of them remain at home on the farm; some leave home to work for wages.

By comparing the number of children living and the number at home, it is possible to estimate the number who have

left home. Since most of the children of those who have been married less than 20 years are not of an age to leave home, the only fair method of comparison is by using the families of parents who have been married 20 years or more. This reveals the fact:

> That although the foreign born had a larger number of children to the family than the natives, they had the smaller number remaining at home;
>
> And also that a smaller percentage of the children of families living on small farms remain at home than of those living on larger farms.

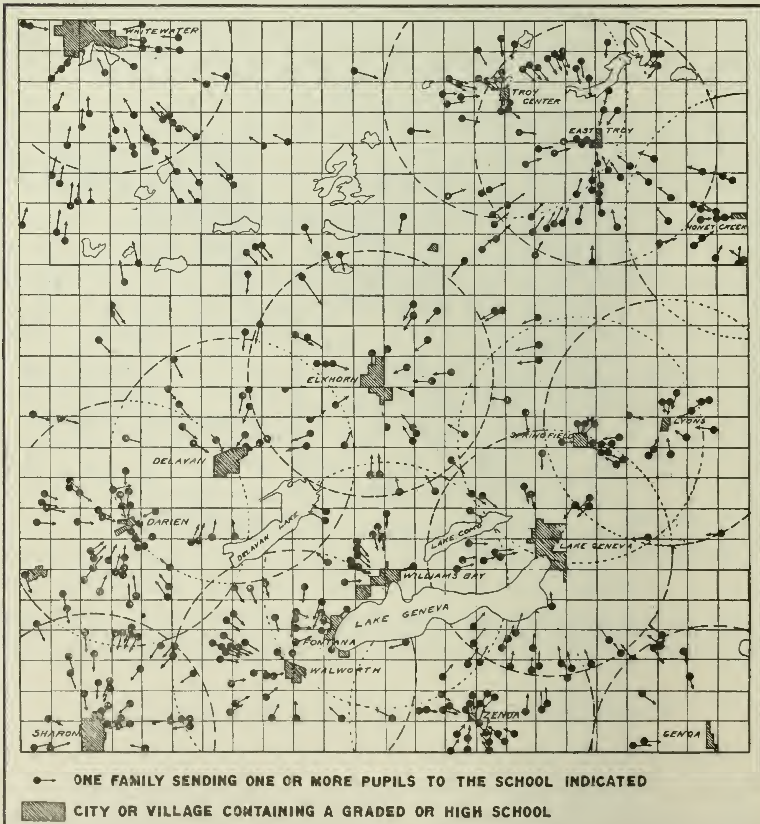

FIG. 18.—MORE SCHOOLS OR BETTER ROADS, WHICH?

Map showing farm homes in Walworth county sending pupils to graded and high schools. Note that 80 per cent of all farms in this county are within a four mile radius of some school offering instruction of a secondary grade. (From data furnished by C. J. Galpin).

A partial explanation for the smaller number of children of foreign parentage remaining at home, is the larger pro-

portion of older children, since it appears that among the natives there is a large proportion of younger children.

It must not be concluded, however, that because the children have left home they have left the rural districts. Yet from independent studies made by others, as well as from a careful study of these statistics, it appears that the larger proportion of those leaving home come from the smaller farms. It is certain that many do go to the cities.

TABLE IV.—NUMBER OF CHILDREN LIVING AND NUMBER AT HOME, BY SIZES OF FARMS, OF TENANTS AND OWNERS WHO HAVE BEEN MARRIED 20 YEARS OR MORE

Size of farms	Tenants		Owners		Total	
	Living	At home	Living	At home	Living	At home
Native						
Under 20 acres	....	....	70	41	70	41
20 to 49 acres	10	8	82	30	92	38
50 to 99 acres	23	14	109	75	132	89
100 to 174 acres	48	35	485	350	533	385
175 to 259 acres	117	83	460	341	577	424
260 to 499 acres	57	48	523	398	580	446
500 acres and over	4	4	75	61	79	65
Total	259	192	1804	1296	2063	1488
Foreign						
Under 20 acres	....	....	67	21	67	21
20 to 49 acres	....	....	106	48	106	48
50 to 99 acres	....	....	223	108	223	108
100 to 174 acres	27	15	507	268	534	283
175 to 259 acres	26	22	236	171	262	193
260 to 499 acres	18	16	186	112	204	128
500 acres and over	7	7	29	21	36	28
Total	78	60	1354	749	1432	809

THE GAP BETWEEN THE FINISHING OF EDUCATION AND THE BEGINNING OF FARMING

From the facts noted above it is evident that only a small percentage of farm boys and girls remain in school after they reach the age of 18 years or the age of high school graduation. The 1910 Census returns for Wisconsin show that less than 3 per cent of the farmers in that state are under 25 years of age, and but 22 per cent are under 35 years of age. The average age of the farmers on the Census date was approximately 46 years. By subtracting from this the average number of years that they have occupied their

farms, it is found that they were between 34 and 35 years of age when they became permanently settled as farmers. A study of statistics collected in Illinois, Iowa, and Indiana shows that farm owners begin farming at the average age of 27.4 years, and tenants at 28.9 years each. In other words, there is an intervening period of at least 10 years between the time that the boy leaves school and the time when he begins farming on his own account, and another period of 6 years before he is settled on a farm that he intends to occupy permanently. This intervening period is sufficient to make him forget much that he learned in school unless the instruction is of a nature that finds immediate practical application.

The Farmer and His Education

In order to determine those things which influence the farmer in his work, and to learn his attitude towards education in general, and agricultural education in particular, a questionnaire was sent to a selected list of Wisconsin's most progressive farmers. Three hundred and fifty replies were received and such answers as could be tabulated have been summarized and the results are here given. Of course there is no way to determine whether these replies are typical of the mental attitude of a majority of the farmers of the state or not, but they do represent the views of the leading dairymen, fruit growers, live stock breeders and seed grain growers from whose organization lists these names were selected.

Sources of Incentive

As it was found that 185 of those who replied to the questionnaire had studied agriculture at Madison, most of them taking the short course, and 165 had never studied agriculture in school, the answers were divided according to those who had studied agriculture at the college and those who had not.

Among the questions asked was, "Do you grow alfalfa and what led you to try it?"

Of the replies of the first group as to sources of incentive,

39, because alfalfa was a good crop to grow on account of its high feeding value.

38, because they had attended the short course.

27, because they had determined that alfalfa would increase the profits of farming.

25, because they had read about alfalfa in the papers.

17, because their neighbors had grown it they were convinced, from their own observations that it was a good thing to grow.

32, reported that they had never tried to raise alfalfa.

Of course, those who had taken the short course showed that this had been a great inspiration to them and in many cases had determined that they should take up the progressive idea. A large number of them give the short course credit in their answers. Those who say that they were induced to grow alfalfa because it had a greater feeding value, or because it would increase profits, do not indicate where they learned these facts.

Of those who had not studied agriculture in school

33 reported that reading papers had been the thing that influenced them to grow alfalfa.

29 reported that the profits from raising this crop caused them to decide in its favor.

16 reported that the success of neighbors had influenced them in making their decisions.

54 of this group reported that they had never tried to raise alfalfa.

In other words, the proportion of those who had never tried to raise alfalfa was twice as great among those who had not studied agriculture as among those who had.

Another question asked was, "Have you any pure bred animals and what led you to purchase them?"

Of those who had studied agriculture, only 21 had no pure bred animals; whereas of those who had never studied agriculture in school, 38 had no pure bred animals. The incentive that seemed to predominate in influencing these farmers to raise pure bred animals was that of profits. The short course had been quite effectual in helping them to form a decision. A characteristic of certain men is that they are proud to have first class animals on their farms and this had decided some to keep this kind of stock. Among those who had never attended the short course, the profits had been the predominating influence. The reading of farm papers seemed to have taken the place of the short course in helping this group to decide to keep pure bred stock.

The third question asked was, "Do you have a silo and what led you to build it?"

Of those who had taken the short course, again the profits seemed to be the deciding point. The next most important incentive was the increase in the feeding value of crops made into silage. The reading of papers had had more influence than the short course. The answers also indicated that the number influenced by neighbors was but little less than the number influenced by the short course.

49 of those who *had* studied agriculture had no silos,
55 of those who had *never* studied agriculture had no silos.

Similarly, among those who had not attended the short course the profits had appealed to them most strongly and the reading of papers had been second in importance. The greater feeding value of silage also appealed strongly to them. The neighbors seemed to have had some influence in helping them to make the decision.

The above comparisons between those who had, and those who had not studied agriculture seem to indicate that those who had studied agriculture in school were adopting progressive ideas more generally than the second group, as shown by the following table:

OF 185 FARMERS WHO HAD STUDIED AGRICULTURE IN SCHOOL

There were but 21 or 11.3 per cent who owned no pure bred animals,
There were but 32 or 17.3 per cent who never tried to grow alfalfa,
There were but 49 or 26.5 per cent who did not have silos.

OF 165 FARMERS WHO HAD NOT STUDIED AGRICULTURE IN SCHOOL

There were 38 or 23.0 per cent who owned no pure bred animals
There were 54 or 32.7 per cent who never tried to grow alfalfa
There were 55 or 33.3 per cent who did not have silos.

A number of additional questions were asked as to whether or not they used pedigreed seed, selected and tested seed corn, weighed and tested milk. The question was then asked:

"What induced you to do the up-to-date things you are doing?"

Here, again, the replies were grouped as to whether or not they had studied agriculture in school.

Those who had attended the short course, indicated that it had been the predominant influence in leading them to adopt advanced practices. The next most important in-

fluence mentioned was the reading of agricultural papers. It was also indicated in their answers that they had personal ambitions to be something as farmers and leaders in their communities, and that this had led them to progress in their agricultural work. The reading of bulletins seems to have played rather a minor part.

Those who had never studied agriculture in school indicated that the reading of papers had been the principal factor in helping them to make their decisions and the reading of bulletins the next in importance. They also mentioned a personal ambition to be something as farmers and leaders in their communities.

It is also worthy of notice that the example of neighbors and the influence of their own children had also caused both groups to progress in their agricultural practices. The influence of children seems to have been stronger among those who had not attended the short course than those who had. This may be due to the fact that the influence of the short course overshadowed all the other factors.

The Influence of the Short Course

A question was asked of those who had attended the short course to determine what things they had studied at the agricultural college that had been put into practice on their farms. The most prominent item was the selecting, testing and use of pure bred seed. The ownership of pure bred stock was the second in importance. The next in importance in the order named were the fundamentals of dairying, the feeding of live stock, better general farming, care of animals, methods of crop rotation, the growing of alfalfa and clover, methods of studying the soil, judging cattle, and the use of the silo.

The Education of the Farmer's Children

It was desired to learn something of the farmer's interest in the general education of his children. The difference in the education of the younger and the older boys brings out one or two very striking points. The adult sons were divided into two groups:

1.—Those between 20 and 29 years of age.
2.—Those over 30 years of age.

Those between 20 and 29 years of age can be considered as having attended school within the last 10 or 15 years, whereas, not many of those who were over 30 can be considered as having attended school within the same period.

It was found that a much larger percentage of those between 20 and 29 years of age who remained at home or who were engaged in farming had attended both high school and college than those of the older group.

Among the younger group of children there were 43 who had attended college. Twenty-six or 60 per cent of these had remained on farms. Of the older group there were 22 who had attended college and but five of these or 22.6 per cent were to be found on farms. Continuing this analysis it was found that a much higher percentage of the younger group of children similarly had high school training.

This seems to indicate the awakening of farmers to a realization of the value of higher education even if their sons are to return to the farm. They have always recognized the necessity for special preparation for professional life.

From the data obtained it was impossible to make similar comparisons of the education of farmers' daughters, though it is evident that a much smaller percentage of them attend higher institutions of learning than do farmers' sons, even though they may have equally good high school training.

The Education of the Farmer's Wife

It has been said that educated women do not marry farmers. The returns show that of farmers' wives over 30 years of age, but 35 per cent of them had an education beyond the common school, while for those under 30 years of age 60 per cent had a high school education or better.

The Influence of Agriculture in the Public Schools

In this study the farmers were asked to give their opinions of the value of agriculture in the public schools. Fifty-nine replied that it was of no value. Either it had not been taught or when it had been taught it had left no impress on the community. Fifty-three stated that their children took more interest in their work both in school and out of it. A

large number believed it to be of value but did not mention in what way.

The specific things taught in the public schools mentioned as of value are arranged in the following list in order of preference:

1.—The use of pure bred seeds.
2.—Testing seed corn.
3.—Growing corn.
4.—The value of pure bred stock.
5.—Testing milk.
6.—Testing seeds in general.
7.—Growing alfalfa.

In comparison with the above it is interesting to note the replies of farmers to the question of value of Boys' and Girls' Club work:

120 indicated that it had increased their children's interest in better farming.
33 replied that it had kept their boys and girls on the farm.
20 frankly acknowledged that it had induced their children's parents to grow better crops, and only
12 replied that club work was of no value.

Superficially it may seem that Boys' and Girls' Club work has been of more influence than the teaching of agriculture in schools, but it must be remembered that club work in Wisconsin is carried on through the schools. It cannot be concluded, therefore, that club work should take precedence over general instruction in the school, but it is evident that if the teaching of agriculture in the schools is to be effective it must be carried into the home.

Suggested Improvements

The farmers were asked to suggest needed improvements in the teaching of agriculture in the public schools. Their replies may be grouped under the following heads:

1.—Need for better prepared teachers,
2.—Need for more practical instruction,
3.—Need for more extensive teaching.

It is evident that this group of Wisconsin farmers thoroughly approve of the teaching of agriculture in the public schools and are ready to further it in every possible way whenever the instruction is of such nature as to meet with their ideals.

EDUCATION AND LAND OWNERSHIP*

Does the quality of his education affect the time necessary for the farmer to acquire free title to his land? For this study the farmers were arranged in two classes as follows:

Class 1.—Those who had a high school education or better.

Class 2.—Those who had a common school education only. Each of these classes were again subdivided into three groups:

1.—Those who had always worked on farms when not in school until they began farming on their own account.

2.—Those who never worked on farms until they began farming on their own account.

3.—Those who had worked both on farms and at other occupations before beginning farming on their own account.

It was found that a much larger proportion of the high school class had never worked on farms or had worked at both farming and something else, before they began farming for themselves than of the common school class.

By what processes had these farmers acquired free title to their land?

1.—The largest number of both classes had started with mortgages on their farms.

2.—The second largest number of both classes had begun as tenants and then acquired ownership through mortgage.

3.—(a) Among the high school class the third group in importance were those who had been tenants but whose farms had never been mortgaged.

(b) Among the common school class the third group in importance had neither been tenants nor had their farms ever been mortgaged.

At what age had these men begun farming on their own account?

1.—Those who had never followed any other occupation than farming began farming at an earlier age than either of the other two groups.

2.—Those who had a high school education began farming over one year later than those who had only a common school education.

3.—It took the man with a common school education who had engaged only in farming 10 years to obtain possession of a clear title.

4.—It took the man with a high school education slightly over seven years to obtain a clear title to his farm. This advantage over the common school group may have been due, however, to superior opportunity or financial advantage.

*Note:—Based on complete data secured from 315 farmers. The numbers given are the averages for the group.

5.—Those who had never farmed began farming on their own account between 8 and 9 years later than those who had always farmed with the result that they owned their farms free from 5 to 8 years later in life than those who devoted themselves entirely to farming.

6.—Those with a common school education began farming at approximately 26 years of age.

7.—Those with a high school education began farming at the age of 27.

8.—Those with a common school education owned their farms free at 36 years.

9.—Those with a high school education owned their farms free at between 34 and 35 years of age.

By comparison of the above observations it is noted that the men with a high school education began farming on their own account one year later but owned their farms free from debt over one year earlier in life. These data apparently indicate that a high school education is a good investment for the farmer and that it pays the boy who intends ultimately to be a farmer to stick by the farm rather than to engage in other occupations.

THE CASH VALUE OF THE FARMER'S EDUCATION*

For the purpose of studying the relation between the farmer's education and his earning capacity, statistics collected on 825 Wisconsin farms during the past two years have been brought together in Table V.

TABLE V.—THE RELATION BETWEEN EDUCATION, INVESTMENT, AND INCOME

Education	Highest school attended			
	Common school	Short course in agriculture	High school	College
Number records studied	478	108	155	84
Average size of investment	$19,958	$22,830	$23,502	$27,577
Income from investment (5 per cent	998	1,241	1,275	1,380
Average labor income	632	739	893	1,056
Total income (Interest on investment and labor income)	1,630	1,980	2,168	2,436
Average value of residence	1,764	1,837	1,939	2,558

*From thesis material compiled by W. O. Lockhart, graduate student in 1915.

LABOR INCOME DEFINED

As here used, labor income is equivalent to net proceeds. In order to ascertain labor income, the total receipts (including increased inventory) are first ascertained. All costs of farm operations, including labor of all members of the farmer's family (except the farmer himself) are then paid. That portion of the family maintenance, obtained directly from the farm is deducted as well as 5% interest on the total capital invested. What remains after these deductions are made, according to this method (now widely used throughout the United States) is termed labor income. This is supposed to represent the amount that the farmer receives for his labor and management during the year.

WHAT THIS STUDY INDICATES

It is apparent from the table that the best educated farmer stands the best chance of making a large income and apparently has the ability to earn a normal rate of interest on a larger investment in agricultural pursuits.

It will also be observed that the farmer with the best education not only receives the largest labor income, as well as total income, but also maintains a higher average standard of living. This latter deduction may be drawn from two sources:

1.—The size of the investment in a place of residence,

2.—The larger use of modern improvements as shown by Table VI.

TABLE VI.—THE RELATION OF EDUCATION TO STANDARDS OF LIVING

Education	Highest school attended			
	Common school	Short course in agriculture	High school	College
Per cent having modern bath rooms	21.9	24.1	27.2	48.5
Per cent having modern lighting systems	17.0	22.1	20.5	44.0
Per cent having furnace heat	22.1	29.7	30.0	47.0
Per cent having automobiles	20.0	23.6	25.4	29.1

EVIDENCE NOT CONCLUSIVE

The farmers on whose farms these records were taken were among the best in each county, i. e., they were a select list. It is entirely possible that in the very process of education itself, classification in native ability, corresponding very closely to these four groups, may have come about by natural selection. This, of course, must remain an open question though a further analysis of the data shows that a very large proportion of the older men are found in the common school group, doubtless, owing to the limited educational opportunity afforded them. In all probability, therefore, gradation according to education came as a result of opportunity rather than as a result of natural selection. These observations should be made the subject of further investigation.

PART III.—TYPES OF AGRICULTURAL SCHOOLS IN WISCONSIN

K. L. HATCH

There are in Wisconsin two types of institutions offering secondary instruction in Agriculture as determined by the sources from which they derive their support:

I.—The county schools of agriculture and domestic economy.

II.—The local high schools.

The county schools of agriculture are supported jointly by county and state while the local high schools derive their revenue largely from local sources with the exception of a small state subsidy ($250) for special instruction in agriculture.

Public education is a well established function of government. Special education for industrial classes is its most recent development. All government functions are, in the end, limited by the power and equity of taxation. If of equal efficiency, that type of education will persist which imposes the lightest burden upon the public. The chief factors which determine relative values are:

I.—The ideals
II.—The curriculum
III.—The distribution of students
IV.—The cost per unit attendance.

IDEALS

It would seem that all institutions engaged in agricultural teaching in Wisconsin are inspired by common ideals. If there be differences in ideals, these are not yet apparent; besides there is no means of accurately determining if such differences do really exist. The matter of ideals must therefore be passed without effort at analysis.

THE CURRICULUM

The curricla of these institutions, so far as agricultural teaching is concerned, are more or less in a state of flux.

That there is a wide variation in the courses of study of both high schools and county schools of agriculture becomes apparent from the most casual examination of their literature.

There is an evident trend, however, on the part of the special schools toward a standard four year high school course whose completion will fit for college. Whether this can be taken to mean a change in the purpose of the special school or simply an enlargement of its scope and function, is still an unsettled question. It may indicate the dominance by customary educational ideals of this particular type of school.

Whatever this trend means, it is true that the differences between high school courses in agriculture and those of the special school are growing less and less apparent.

DISTRIBUTION OF STUDENTS

The value of any educational institution to the masses is directly proportional to its accessibility, as has already been shown in connection with the study of school attend-

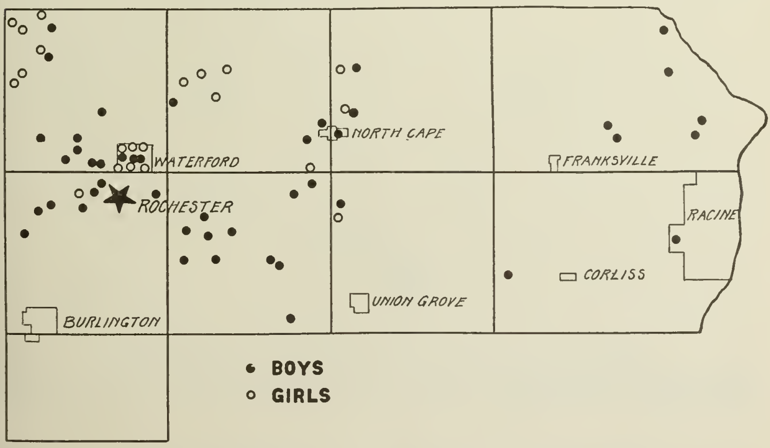

FIG. 19.—WHERE THE STUDENTS COME FROM

Each dot represents the location of one student attending the Racine County School of Agriculture, located at Rochester. In addition 14 students were in attendance from other counties.

ance in Iowa county and as is further emphasized by the accompanying map.

A study of the distribution of student attendance reveals the fact that distance from school, good roads, and other

means of transportation are important factors in determining the attendance in educational institutions. A comparison of the maps showing distribution of students attending the Racine County School of Agriculture and the Richland Center High School appears to show that type of institution has little effect upon student attendance. These maps

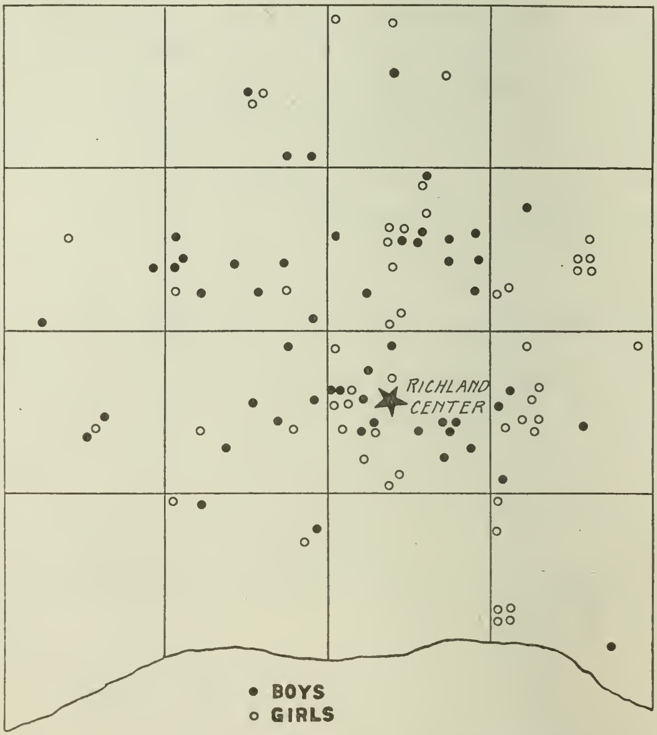

FIG. 20.—LOCATION OF HOMES OF STUDENTS

Each dot represents the home of one pupil attending the Richland Center High School. In addition 4 pupils came from outside the county. Compare this map with the preceding.

do not indicate the number in attendance from the towns in which these schools are located but show the general rather than the local influence of these institutions.

Similar studies made by others are corroborative of the conclusion that type of institution is of far less importance in determining its radius of influence than is its accessibility.

THE COST OF INSTRUCTION

Below are submitted data showing annual cost of instruction, per student enrolled, in the two types of secondary agricultural schools in Wisconsin. It is recognized that these figures are not wholly comparable but they will at least serve as a basis for judgment as to the relative cost of agricultural education in these institutions.

TABLE VII.—COST OF INSTRUCTION AND MAINTENANCE PER STUDENT IN THE COUNTY SCHOOLS OF AGRICULTURE AND DOMESTIC ECONOMY FOR THE YEAR ENDING JUNE 30, 1915

School	Cost of instruction (only)	Cost of maintenance	Total
A	$98.71	$85.49	$184.20
B	127.14	69.78	196.92
C	166.26	95.61	261.87
D	214.28	54.26	268.54
E	150.78	140.14	290.92
F	152.38	205.29	357.67
G	152.30	207.43	359.73
Average	151.69	122.57	274.26

Based on average daily attendance.

It should be added that several of these institutions are carrying on business operations in connection therewith. The income from the business, as shown by the annual reports to office of the State Superintendent of Public Instruction, has been deducted in each instance before dividing maintenance among the average number of students in attendance for the year. The figures, therefore, represent net cost for instruction and maintenance which must be raised by public taxation. Revenue from the business operations carried on by these institutions does not necessarily represent profit. This item will be affected by the system of bookkeeping in vogue in each institution.

It must be remembered that some of these schools have developed extension work, so that this activity now consumes a considerable portion of the time of their instructors. However, no statistics, showing the relative proportion of time spent in teaching and extension, are available. The instructors are usually hired by the year while the law requires but eight months of actual teaching. If we assume, therefore, that one-third of the cost of instruction in these schools

is chargeable to extension work, we have only to take two-thirds of the amounts shown in the above tables to find the actual cost of instruction of students in these institutions.

TABLE VIII.—COST OF INSTRUCTION AND MAINTENANCE PER STUDENT IN HIGH SCHOOLS FOR THE YEAR ENDING JUNE 30, 1915

	Highest	Lowest	Average
Cost of instruction	$103.84	$29.65	$44.22
Cost of maintenance	67.15	13.56	25.00

Based on average daily attendance in 75 high schools receiving state aid for instruction in agriculture.

The statistics from which the costs of instruction were computed are complete for each of the seventy-five schools. In order to compute the cost of maintenance it was necessary to base the calculations wholly upon data furnished by township and union high schools. These schools are required by law to keep separate accounts even if associated with the grades of the village in which the high school is located. In the case of district high schools the cost of maintenance is so involved with that of the graded school system that reliable statistics could not be obtained. It was, therefore, impossible to calculate averages for the whole group so far as maintenance is concerned. Totals are necessarily omitted.

A better idea of the costs of instruction in these seventy-five high schools can be obtained by arranging them in groups as follows:—

Cost per student	Number schools
Below $30	1
$30 to $40	16
$40 to $50	25
$50 to $60	13
$60 to $70	12
$70 to $80	3
$80 to $90	3
$90 to $100	1
*Over $100	1

*This school had a total enrollment of sixteen students.

The average daily attendance in each of the eight schools showing the highest cost of instruction per student (over $70)

was 13, 33, 21, 32, 27, 55, 30 and 31, respectively.* The average daily attendance in each of the eight schools showing the lowest cost of instruction per student ($35 or less) was 234, 178, 274, 93, 53, 301, 167, and 92, respectively.*

HIGHER COST OF AGRICULTURAL INSTRUCTION

While supporting statistics are insufficient to warrant definite deductions, it is unquestionably true that the addition of so-called "vocational" subjects to the curriculum of any school increases the per capita cost of both instruction and maintenance.

The increased cost due to the introduction of agriculture into the curricula of small schools must be offset (so far as is possible) by the elimination of less important subject matter—if agriculture is to have a permanent place in our system of education.

*Arranged in order of cost, highest to lowest, lowest to highest.

Parts I and II of this bulletin were prepared by Eugene Merritt, Assistant in Agricultural Education, States Relations Service, United States Department of Agricluture, and K. L. Hatch, Professor of Agricultural Education in the College of Agriculture of the University of Wisconsin, under supervision of C. H. Lane, Chief Specialist in Agricultural Education for the United States Department of Agriculture. Valuable assistance was rendered by Jesse A. Van Natta, Superintendent of Schools of Iowa county, and O. C. Stine, a graduate student in the University of Wisconsin in the compilation of the material used in this publication, particularly that on the rural schools of Iowa county.

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The Utilization of Phosphates by Agricultural Crops, Including a New Theory Regarding the Feeding Power of Plants

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OF THE UNIVERSITY OF WISCONSIN

MADISON, WISCONSIN

CONTENTS

The Utilization of Phosphates by Agricultural Crops, including a New Theory Regarding the Feeding Power of Plants*

Although compared to the Eastern part of the United States and especially to Europe, the oldest farmed soils of Wisconsin have been cropped only a comparatively short time, yet conclusive field tests show that many of these Wisconsin soils are already badly in need of phosphate fertilizers. This, together with the enormous consumption of phosphate fertilizers in Europe, points unmistakably to a time in the near future when Wisconsin must also use large amounts of these fertilizers if the productivity of her soils is to be maintained. Accurate knowledge regarding the most economical methods of phosphate fertilization and of maintaining the soil phosphates in a condition in which the crops may readily use them, under the particular Wisconsin soil conditions, is thus a matter of great practical importance. An investigation of this subject was thus started several years ago and the present bulletin is a progress report of the investigation. Along certain lines definite additions to our knowledge have been made and are reported herein.

In a former bulletin[1] data ~~was~~ Were presented supporting the general contention that decaying organic matter exerts a solvent action on raw rock phosphate and thus increases its availability to crops. In connection with the previous investigation four important questions, which were not as completely answered in the literature as desired, arose: viz.;

(1) What differences are there in the direct feeding powers of the common agricultural plants for raw rock phosphate?

*The investigation reported in this bulletin has been in progress since 1911, during which time the writer has received a large amount of assistance on this subject from various sources. The writer is indebted to Professor A. R. Whitson for suggestions, criticisms, and facilities for carrying on the work, and to A. L. Buser, C. F. Frye, A. N. Johnson, O. J. Noer, C. B. Post, C. Thompson and T. Y. Tang for valuable assistance, each of whom worked on some phase of the subject in fulfillment of the bachelor's thesis. The writer is especially indebted to T. Y. Tang, Fellow in Soils (1913–14), whose painstaking efforts in plant house and chemical work contributed very materially to the results.

[1] Wis. Expt. Sta., Research Bul. 20. Published January, 1912.

(2) What is the general underlying cause for such differences as exist in the feeding powers of plants?

(3) What is the action of accompanying fertilizers on the availability of rock phosphate?

(4) What differences are there in the availabilities to agricultural plants of the various phosphates commonly assumed to be present in soils?

Questions (1), (2), and (3) have an important bearing on the use of raw rock phosphate, especially in planning systems of rotation which are best adapted to make use of this form of phosphate and in the interpretation of plant house and field experiments on this subject. The last question has a direct bearing on the ultimate availability of phosphorus applied in different phosphate fertilizers, for phosphates, whether applied in soluble forms or in forms that become soluble by means of the processes taking place in soils, are eventually, to a large extent, precipitated in combination with the various bases existing in soils. A type set of reactions which undoubtedly take place when rock phosphate is applied to soils may be represented as follows:[2]

(1) $Ca_3(PO_4)_2 + 2H_2CO_3 \rightleftarrows Ca_2H_2(PO_4)_2 + CaH_2(CO_3)_2$

(2) $Ca_2H_2(PO_4)_2 + 2Fe(OH)_3 \rightleftarrows 2FePO_4 + 2Ca(OH)_2 + 2H_2O$

Other bases: e.g., magnesia, alumina and possibly in certain cases manganous oxide, may take the place of the ferric oxide in the second reaction and form the corresponding phosphates. The presence of considerable calcium carbonate in the soil may cause a reversion back to tricalcium phosphate. Phosphates made soluble by the first reaction may be taken up directly by growing plants without entering into the second reaction.

Due, however, to the facts that the feeding roots[3] of a plant, at any one time, come into contact with only a small portion of the internal surface of the soil, and that a plant takes up only a limited amount of phosphorus, it seems probable, that at least in acid soils, reactions similar to number (2) proceed to some extent during the entire growing season. The application of phosphates in soluble forms pre-

[2] In this connection see the work of Georgievics, Monatsch. f. Chem. 12 (1891) 566.

[3] See Nobbe, Landw. Vers. Sta., 52 (1899) 473.

sents very favorable conditions for reactions of type number (2) to take place. The availability to plants of the different phosphates formed according to the second reaction is thus of considerable interest and importance and has previously attracted the attention of a number of investigators.

Historical Summary

Since the early writings of Liebig[4] on the role of the plant itself, in making mineral elements available, the report of Sachs'[5] experiment in 1860 which demonstrated that plant roots are able to corrode marble plates, and the report of Czapek's[6] extensive investigations in 1896 which indicated that carbonic acid is the only acid given off in considerable amounts by live plant roots, many experiments have been reported on the feeding power of plants, in which the insoluble phosphates were mixed with a soil medium consisting of quartz sand.

One of the earliest extensive investigations with phosphates in which quartz sand was used is reported by the Maine Experiment Station, where at first Balentine[7] and later Merrill[8] investigated the subject. Merrill used acid phosphate, rock phosphate and redondite (a phosphate of aluminum and iron), in quartz sand cultures and grew eighteen species of plants. He found that acid rock gave the best returns in all cases and especially with the graminae. With graminae, redondite gave better results than rock phosphate, but in other cases the reverse was true. Plants of the cruciferae family were especially strong feeders on rock phosphate. Balentine states that the sand used contained 0.012 per cent of phosphoric anhydride and Merrill also states that it contained traces of phosphorus in an insoluble form. Apparently the presence of this phosphorus, introduced by the sand itself, has been more of a disturbing factor than might at first be supposed. With many of the plants the blanks gave as large, and in several cases larger, growths than those which received rock phosphate and redondite. On the average the growths of the blanks were nearly one-half as large as the growths of those that received

[4] Ann. Chem. U. Phar. 105 (1858) 139.
[5] Bot. Zeit. 1860, 117.
[6] Jahrb. Wissen. Bot. 29 (1896) 321.
[7] Maine Expt. Sta., Ann. Rept. (1893) 13.
[8] Maine Expt. Sta., Ann. Rept. (1898) 65.

acid phosphate, indicating that at least some of the plants made considerable use of the phosphorus originally present. Notwithstanding this disturbing influence, the Maine investigations bring out conclusively the remarkable differences that exist in the foraging power of different species of plants for insoluble phosphates.

Some of the most extensive and important experiments reported dealing directly with the subject under discussion are those by Prianischnikov.[9] After conducting elaborate pot culture investigations on this subject with quartz and soil over a period of more than ten years he concluded that the availability of a fertilizer is influenced by the nature of the plant, the soil, the fertilizer, and by the interaction of accompanying fertilizers.

Prianischnikov classified plants into two groups as regards their feeding power on phosphorite.* Lupines, peas, buckwheat, and mustard were placed in the group having a strong feeding power and cereals in the group having a weak feeding power.

He also found as follows: Phosphorite was much more effective as a source of phosphorus when used on acid soils than when used on the non-acid ones. The addition of ¼ to 1 per cent of calcium carbonate to the cultures resulted in a greatly decreased availability of the phosphorite, but usually did not materially effect the availability of dicalicum phosphate, mono-potassium phosphate, Thomas slag and iron and aluminum phosphates. The use of ammonium nitrate or a combination of ammonium sulphate and sodium nitrate instead of sodium nitrate as a source of nitrogen resulted in a greatly increased availability of the phosphorite to plants having weak feeding powers even when moderate amounts of calcium carbonate were added. The phosphorus of precipitated iron and aluminum phosphates was found to be readily available to plants.

The results showing that plants could obtain their required phosphorus from precipitated iron and aluminum phosphate was at first taken by Prianischnikov[10] as an indication that either plants secrete other acids than carbonic or else carbonic acid has a more marked solvent action on these

[9] Landw. Vers. Sta., 56 (1902) 107; Ibid, 65 (1907) 23; Ibid, 75 (1911) 357; Ber. Deut. Bot. Gesel. 22 (1904) 184.
*The term phosphorite is used in Europe in place of rock phosphate.
[10] Ber. Deut. Bot. Gesel. 22 (1904) 184.

phosphates than it is supposed to have. Later he learned that pure water has a sufficiently marked solvent action by hydrolysis on these phosphates to account for the availability of their phosphorus to plants.[11] He then pointed out the unsuitability of these phosphates for demonstrating acid root excretions. The correctness of Czapek's conclusion, that plants excrete no other free acids than carbonic, is not disputed but simply the method of proof, in which aluminum phosphate was used.

Prianischnikov found that when the nitrogen was supplied as sodium nitrate, the cultures usually became alkaline, when as ammonium nitrate, neutral, and when as ammonium sulphate, acid. The increased availability of phosphorite when used in conjunction with ammonium salts over that when sodium nitrate had been used was explained by him as follows: Ammonium sulphate probably functions as a physiologically acid salt and sodium nitrate as a physiologically basic salt. That is, plants by using more of the basic part of ammonium sulphate than of the acid part leave an acid residue which makes the phosphorite available; and by using more of the acid part of sodium nitrate than of the basic part, leave a basic residue which has an unfavorable action on the availability of phosphorite. The favorable action of ammonium nitrate is also probably due to its action on the physiological activity of the plant. It may make possible the regulation of the reaction of the nutrient medium, since the plant may take its nitrogen either from the acid or basic part of the salt and thus prevent an overbalance of bases which act unfavorably on the availability of phosphorite or an overbalance of acids which act unfavorably on plant growth.

In 1899, Schloesing[12] reported the results of pot experiments with quartz sand which showed that plants can obtain their phosphorus from very dilute solutions, that is, solutions containing only one to two milligrams of phosphoric anhydride per liter. Wheat, corn, beans, and buckwheat were grown in these experiments. The importance to the plant of the phosphates naturally dissolved in the soil solution is pointed out.

P. Kossowitsch and his assistants during a period of about

[11] Landw. Vers. Sta. 75 (1911) 372.
[12] Ann. Sci. Agron. T. 1 (1899) 321.

10 years carried on very extensive and valuable experiments dealing directly with the subject under discussion. In 1898 and 1900, Kossowitsch[13] reported the results of experiments with quartz cultures, showing that there is a great difference in the feeding power of different species of plants for phosphorite. Evidently the quartz used contained some phosphorus since the blanks in many cases gave a considerable growth. In 1901 he[14] reported the results of pot experiments with a soil that needed a phosphate fertilizer. These results show that all the plants which were grown used the phosphorus of phosphorite to a considerable extent. The mustard and buckwheat exhibited especially strong feeding powers, making nearly as large growths with phosphorite as with Thomas slag.

In 1902, Kossowitsch[15] reported the results of experiments on the role of plants in dissolving insoluble plant food materials. Phosphorite in quartz cultures was used for the insoluble material. The special point in these experiments was the determination of the solvent action of the plant roots themselves, aside from the solvent action which the nutrient solution might exert. This was accomplished in the following way with two sets of cylinders: In the first set the plants were grown in a cylinder in which the phosphorite was mixed with the sand, and five litres of nutrient solution were allowed to pass through daily. In the second set the plants were grown in a cylinder which contained no phosphorite, but received the nutrient solution after it passed through a cylinder that contained quartz and phosphorite, but on which no plants were growing. In the second set the plants made very little growth compared to the first set showing that the plant roots themselves and not the nutrient solution were active in making the phosphorite available.

Kossowitsch also repeated experiments similar to those of Schloesing, and obtained similar results. Peas, flax and mustard were grown. Flax which, relatively, had little power to utilize the phosphorus of phosphorite made a considerable growth when the nutrient solution applied contained only 1.3 mgm. of phosphoric anhydride per liter, indicating that the relative feeding power of plants for phos-

[13] Compte. rendu du Lab. agron. du Minist. de l'agr 1898, 226 and Russ. Jr. Expt. Landw. 1 (1900) 657.
[14] Russ. Jr. Expt. Landw. 2 (1901) 730.
[15] Russ. Jr. Expt. Landw. 3 (1902) 145.

phorite is not determined solely by their ability to utilize the phosphates of dilute solutions.

In this same report Kossowitsch stated that the solvent action of plants is probably mainly due to the carbonic acid which the roots excrete, and differences in feeding powers of different species of plants are probably due to differences in the amount of carbonic acid excreted by the roots.

In 1904 and 1906, Kossowitsch[16] reported the results of experiments on the quantitative determination of the amounts of carbonic acid excreted by the roots of mustard, barley and flax plants. The roots of all three species of plants gave off very notable amounts of carbonic acid, but the differences in amount did not allow the drawing of any definite relations between the feeding powers of plants and their capacity to excrete carbonic acid.

In 1904, Kossowitsch[17] reported the results of carefully controlled experiments relative to the effect of ammonium salts on the availability of phosphorite. The possibility of nitrification being a factor was carefully controlled. The results confirmed those of Prianischnikov which have already been given.

In 1909, Kossowitsch[18] reported a summary of his work on the utilization of phosphorite by mustard, clover, oats and flax, involving the use of acid and non-acid soils, and also calcium carbonate. When the phosphorite was applied to decidedly acid soils, all of the plants exhibited marked powers to utilize the phosphorus therein. As regards their relative feeding powers to utlize phosphorite the four plants stood in the following order: mustard, clover, oats, and flax. Under alkaline conditions of soil this power of mustard to utilize the phosphorite was not markedly reduced but with the other plants it decreased decidedly. As regards the utilization of the phosphorus naturally present in the soil the plants showed an entirely different order of feeding powers than for phosphorite. In this case oats and flax had the strongest feeding powers and mustard the lowest.

In conclusion Kossowitsch stated that the subject is very complicated and many factors need to be taken into consideration in order to explain the utilization of various phos-

[16] Russ. Jr. Expt. Landw. 5 (1904) 493 and 7 (1906) 251.
[17] Russ. Jr. Expt. Landw. 5 (1904) 598.
[18] Russ. Jr. Expt. Landw. 10 (1909) 839.

phates by different plants. He did not offer explanations for many of the various experimental results that he had obtained.

Nagaoka[19] investigated the immediate and after effect of applying various phosphates to soil cultures on the growth of rice plants. The experiment was carried on for a period of four years and the soil had been previously exhausted. Different phosphates were used as follows: double superphosphate as a standard, ferric phosphate, ferrous phosphate, aluminum phosphate, and tricalcium phosphate. The order of efficiency of the different phosphates over the four year's period as indicated by the growths produced is given in Table I.

TABLE I.—ORDER OF EFFICIENCY OF DIFFERENT PHOSPHATES OVER FOUR YEARS' PERIOD

Year	Super-phosphate	Ferric phosphate	Ferrous phosphate	Aluminum phosphate	Tricalcium phosphate
First	3	1	5	4	2
Second	4	2	5	1	3
Third	5	2	3	1	4
Fourth	3	4	5	2	1

These results indicate that ferric and aluminum phosphates were quite effective on this soil in supplying the rice plant with phosphorus. However, it is important to note that the ferric phosphate became less available to succeeding crops while the tricalcium phosphate in comparison to the other phosphates showed the highest availability the fourth year.

Elliot and Hill[20] found that in many cases ferric and aluminum phosphates were superior to calcium phosphate. The amounts of phosphates used and the growths secured were, however, too small and preclude the drawing of conclusions.

Jordan[21] carried on experiments much similar to those by Merrill of Maine, and confirmed Merrill's results.

After conducting extensive investigations on the phosphate needs of Texas soils, Fraps[22] concluded that among several things the nature of the plant which is used as the

[19] Bul. Col. Agr., Tokyo, Imp. Univ., 6 (1904) 215.
[20] Va. Expt. Sta., Ann. Rept. (1909–10) 144.
[21] N. Y. Agr. Expt. Sta. Bul. 358 (1913).
[22] Jour. Am. Chem. Soc. 28 (1906) 823. See also Bul. 126, Texas Agr. Expt. Sta.

indicator in pot tests is an important factor in the interpretation of the results obtained, and correlation with data of chemical analyses.

Wheeler[23] and his associates at Rhode Island have conducted extensive field investigations with different phosphates. The results bring out marked differences in the utilization of the various phosphates by the different species of plants.

Lately Burlison[24] of Illinois has reported the results of extensive quartz pot culture investigations on the utilization of rock phosphate by several crops. Since he supplied the nitrogen in the form of ammonium nitrate, the results must be carefully considered, keeping in mind the marked influence of ammoniun salts on the availability of rock phosphate. In this connection see Table XV.

No pretense is made at having given a complete list of references that have a bearing on the four questions stated on pages 1–2. It is believed, however, that the references given are among the most important, and that they cover the field in such a way that further references would add little to what has already been said. References to field investigations have been largely purposely avoided, since such investigations cannot be controlled sufficiently to furnish data for establishing the basal and fundamental principles underlying this subject. This is no reflection on field experiments as it is clearly recognized that they are all important in testing out the practical application of scientific investigations along these lines.

The status of knowledge at the time the present investigation was started regarding the four questions previously stated may be summarized as follows:

(1) Investigations had shown that great differences exist in the feeding power of agricultural plants for rock phosphate, but determinations of this feeding power for many of the common agricultural plants under adequately controlled conditions had not been made.

(2) A satisfactory explanation why different species of plants should vary so much in their feeding power had never been given.

(3) The greatly increased availability of the phosphorus

[23] R. I. Agr. Expt. Sta. Bul. 118 and 163.
[24] Jour. Agr. Res. VI (1916) 485.

in rock phosphate when used in conjunction with ammonium salts had not been fully explained.

(4) It had been frequently stated that the phosphorus of soils in the form of iron and aluminum phosphates is of very low availability to plants, although the experiments of several investigators cited showed conclusively that precipitated iron and aluminum phosphates serve as readily available sources of phosphorus for plants, including even those that are weak feeders on rock phosphate. This had not been explained satisfactorily.

It was primarily for the purpose of supplementing the knowledge regarding these four questions that the present investigation was undertaken.

In a preliminary report in 1912 the writer[25] in discussing the solution of soil phosphates and the feeding of plants, pointed out that the progress of the reactions involved are best explained by means of the law of mass action and chemical equilibrium. In the solution of rock phosphate by the carbonic acid given off by decaying organic matter and live plant roots it was indicated that in order for the reaction to continue indefinitely both of the products of the reaction (calcium acid phosphate and calcium bicarbonate) must be removed either in the drainage water or by the roots of growing plants. This naturally led to the possibility of finding a relationship between the feeding powers of different plants for the phosphorus of rock phosphate and the calcium oxide content of these plants. That is, plants which are strong feeders on rock phosphate should have a higher calcium oxide content than those that are weak feeders. In applying this hypothesis to the experimental results of pot cultures, it was found to agree in all but a few cases. The publication of this as a theory regarding the feeding power of plants was thus, because of these few cases, delayed until

[25] Wis. Agr. Expt. Sta. Res. Bul. 20. On page 46 there is stated as follows: "It is most important to recognize that the carbon dioxide given off by the plant roots exercises its solvent action under conditions which have never been imitated in the laboratory. The reaction proceeding when carbon dioxide acts on phosphates must be considered as of the nature of a balanced action." Also on pages 49–50 there is stated as follows: "In the composting experiments, the dissolved phosphates and carbonates are not removed from the field of action and hence the reaction bringing phosphates into solution quickly reaches a state of equilibrium, after which any further production of carbon dioxide is dissipated to the atmosphere and aids nothing in bringing phosphates into solution.

"Under field conditions the movements of soil water and the feeding of crops are constantly removing dissolved phosphates and carbonates from the little centers of solution existing as fragments of organic material where intensive carbon dioxide production takes place. This continued removal of the dissolved substances results in conditions under which the efficiency of carbon dioxide as a solvent is greatly increased."

what appeared to be exceptions could be satisfactorily explained. From further pot culture experiments, very satisfactory explanations were obtained as indicated in detail on page 29, and accordingly in 1915 the writer published a report entitled, "A New Theory Regarding the Feeding Power of Plants."[26] In this report the following statement was made: "Plants containing a relatively high calcium oxide content have a relatively high feeding power for the phosphorus in raw rock phosphate. For plants containing a relatively low calcium oxide content the converse of the above is true. A calcium oxide content of less than 1 per cent may be considered relatively low. Corn, oats, rye, wheat and millet belong in this class. A calcium oxide content of somewhat more than 1 per cent may be considered relatively high. Peas, clover, alfalfa, buckwheat and most of the species of the cruciferae belong in this class."

In 1914, Chirikov[27] published a very important report, the conclusions of which confirm the views expressed by the writer in 1912, regarding the balanced nature of the solubility reactions in the solution surrounding the plant roots. With this principle as a basis, Chirikov states that the power of a plant to utilize the phosphorus of phosphorite depends upon the ratio of the plant's content of calcium oxide to phosphoric anhydride. He states that in case this ratio is greater than three, marked utilization of .the phosphorite takes place, and in case it is less the utilization is much lower. As indicated by Chirikov there are a considerable number of exceptions to this rule. These, he stated, need further investigation. As already indicated, the writer believes that the calcium oxide content of the plant and not the ratio to phosphoric anhydride is the more important thing to consider. A full discussion of this question is given in the latter part of the present report.

$PO_4^{\equiv}$

EXPERIMENTS ON THE UTILIZATION OF DIFFERENT PHOSPHATES

Subsequent to the results of experiments reported in Research Bulletin 20 of this Station on the "Factors Influencing the Availability of Rock Phosphate," extensive pot culture investigations were started to test the availability to

[26] Science 41 (1915) 616.
[27] Russ. Jour. Exp. Landw. 15 (1914) 54.

various agricultural crops of the different phosphates that probably exist in soils, as indicated on page 2. These investigations were carried on over a period of four years and the tests were not only carried out in duplicate and triplicate but a considerable number were also repeated during a second season. A considerable number of the plants grown were later analyzed for the purpose of obtaining data which might throw some light on the use of phosphorus by plants.

Materials used in greenhouse pot cultures.—Glazed earthenware pots of two and four gallon capacity were used as containers of the soil medium. The soil medium consisted of a very pure natural quartz sand which analyzed 99.13 per cent of silica, and contained only a mere trace of phosphorus in an insoluble form. The extremely small growths obtained on the pots to which no phosphate had been added, showed that the plants were unable to secure appreciable amounts of phosphorus from the quartz sand and that the sand was admirably adapted for experiments of this kind.

The phosphates used consisted of the following: acid phosphate, rock phosphate, ferrous phosphate, ferric phosphate, tricalcium phosphate, aluminum phosphate, manganous phosphate and trimagnesium phosphate. The acid phosphate and rock phosphate consisted of the actual materials sold on the market as commercial fertilizers. The acid phosphate contained 6.54 per cent of phosphorus. The rock phosphate consisted of high grade, finely ground material and contained 15.40 per cent of phosphorus. The ferrous phosphate was purchased as C.P. material. All the other phosphates were carefully prepared in the laboratory by precipitation from the respective C.P. salts. They were thoroughly washed, air dried and powdered, and then dried at 107° C. for 48 hours. The material in each case was then ground to a fine powder and analyzed.

The nutrient solution used except where otherwise stated was made up according to the following formula:

KNO_3	1000 grams
$NaNO_3$	500 grams
$CaCl_2 \cdot 2H_2O$	475 grams
$MgSO_4 \cdot 7H_2O$	225 grams

The above amounts of salts were dissolved in water and diluted to a volume of 25 liters. Smaller lots were made up

with proportionate amounts of salts and water. The iron was supplied from a separate solution of ferric chloride.

Arrangement and care of pot cultures.—Eleven and four-tenths kgm. of the quartz sand were used with the two gallon jars and 22.8 kgm. with the four gallon jars. The weight of the empty jars was also recorded in order that the moisture content later on might be checked and the watering regulated. Except in the case of acid phosphate the phosphates were all added to the sand in such amounts as to give 0.0065 per cent of phosphorus. These applications are approximately equivalent to an application of 1000 pounds of rock phosphate per acre. The acid phosphate because of its solubility was added in an amount which gave one-half as much phosphorus as the others. This was amply sufficient to supply the needs of the plants.

In order to secure thorough mixing, the samples of phosphates were first mixed with about 1 kgm. of the quartz sand and this was then mixed with the remainder of the sand in a large mixing pan.

Uniform seed of high germinating power was selected in the case of the different plants grown. More seed than the desired number of plants was sown in each case. Soon after the plants were up, the weakest ones were pulled out in order to have uniformly strong plants in each case. For each variety the same number of plants were left per jar. In the case of the two gallon jars, the corn was thinned to three plants per jar, cereals to 16 plants and alfalfa to 20 plants. The other plants were thinned out proportionately depending on the kind of plant.

Twenty-five cubic centimeters of nutrient solution were applied on the two gallon pots as soon as the plants came up. Twice this amount was used with the four gallon pots. Further applications of nutrient solution were made depending on the needs as indicated by the growths which had been made. In applying the nutrient solution each application per jar was always diluted with about 500 cc. of water in order to insure adequate distribution of the salts.

Distilled water was used for watering. This was applied frequently, the aim being to keep the moisture content approximately at 13 per cent of the weight of the sand. The pots were supplied with a drainage outlet at the bottom

which prevented injury from any possible over supply of water. The moisture content was checked from time to time by weighing the pots.

The plants were grown in a greenhouse in which a special attempt was made to regulate the temperature and ventilation. The period of growth from planting to harvesting usually ranged from 60 to 75 days with most of the different species of plants. No attempt was made to grow plants to complete maturity, since for some of the plants, the pots used were too small to allow this; and since with most of the plants it is believed that the feeding power is indicated quite reliably by a growing period of 60 to 75 days. A longer growing period is probably objectionable in many cases, since a confined growing space itself may become the prime limiting factor to the further growth of an already fairly large plant. As is later pointed out, a longer growing period than 60 to 75 days is required by some of the small seeded plants that develop very slowly at the start.

At the desired stages the plants were cut off and in some cases the roots were also washed out. The plants were placed in paper sacks and after being thoroughly dried in the air or in an oven at a low temperature, they were weighed. The weights obtained with different treatments are given in the following tables. The results of several pots were discarded due to abnormal variations from other replicates.

TABLE II.—AIR-DRY WEIGHTS IN GRAMS OF OATS PRODUCED WITH PHOSPHATES INDICATED

Kind of phosphate	Tops				Roots				Average weight of total crop	Per cent of standard
	A	B	C	Av.	A	B	C	Av.		
Blank	1.9	2.7	1.8	2.1	1.9	3.6	2.8	2.8	4.9	6.8
Acid	46.3	52.1		49.2	22.0	22.5		22.3	71.5	100.0
Raw rock	3.0	3.8	3.8	3.5	3.4	2.6	2.9	3.0	6.5	9.1
Tricalcium	30.0	28.0	39.0	32.3	16.7	18.5	19.0	18.1	50.4	70.5
Aluminum	42.0	43.9	50.0	45.3	27.5	23.1	20.2	23.6	68.9	96.4
Ferrous	40.9	40.1	36.7	39.2	19.2	20.9	20.2	20.1	59.3	82.9
Ferric	40.0	31.9	39.9	37.3	18.1	21.8	19.4	19.8	57.1	79.9

(See Fig. I.)

TABLE III.—AIR-DRY WEIGHTS IN GRAMS OF CORN PRODUCED WITH PHOSPHATES INDICATED

Kind of phosphate	Tops				Roots				Average weight of total crop	Per cent of standard
	A	B	C	Av.	A	B	C	Av.		
Blank	1.6	2.2	2.0	1.9	1.1	1.7	2.0	1.6	3.5	3.8
Acid	64.3	79.9		72.1	14.7	20.0		17.3	89.4	100.0
Raw rock	2.7	3.2	2.8	2.9	2.2	2.2	2.0	2.1	5.0	5.6
Tricalcium	33.7	31.8	24.9	30.1	15.2	11.7	10.3	12.4	42.5	47.5
Aluminum	67.8	63.2		65.5	19.1	20.2		19.6	85.1	95.2
Ferrous	15.9	15.8	18.3	16.6	6.9	7.8	8.0	7.6	24.2	27.1
Ferric	10.6	10.6	11.1	10.8	4.9	4.6	6.7	5.4	16.2	18.1

(See Fig. 2.)

TABLE IV.—AIR-DRY WEIGHTS IN GRAMS OF RAPE PRODUCED WITH PHOSPHATES INDICATED

Kind of phosphate	Tops				Roots				Average weight of total crop	Per cent of standard
	A	B	C	Av.	A	B	C	Av.		
Blank	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.8
Acid	18.6	19.9	23.7	20.7	5.5	4.0	4.0	4.5	25.2	100.0
Raw rock	4.6	12.6	8.2	8.5	1.2	3.6	5.2	3.3	11.8	46.8
Tricalcium	15.2	15.0	16.4	15.5	2.3	5.8	3.1	3.7	19.2	76.2
Aluminum	15.8	32.3	16.9	21.7	2.7	3.9	1.2	2.6	24.3	96.4
Ferrous	11.7	12.5	13.1	12.4	4.4	2.7	2.1	3.1	15.5	61.5
Ferric	1.4	5.1	6.2	4.2	0.3	2.6	2.2	1.7	5.9	23.4

(See Fig. 3.)

TABLE V.—AIR-DRY WEIGHTS IN GRAMS OF BUCKWHEAT PRODUCED WITH PHOSPHATES INDICATED

Kind of phosphate	Tops				Roots				Average weight of total crops	Per cent of standard
	A	B	C	Av.	A	B	C	Av.		
Blank	0.9	0.8	0.8	0.8	0.1	0.1	0.1	0.1	0.9	3.6
Acid	32.4	17.4	16.5	22.1	2.5	1.4	1.7	1.9	24.0	100.0
Raw rock	16.4	14.0	13.9	14.8	2.0	1.9	2.1	2.0	16.8	70.0
Tricalcium	15.2	14.3	14.4	14.6	2.7	2.2	2.3	2.4	17.0	70.1
Aluminum	18.8	17.2	18.9	18.3	3.6	2.3	2.6	2.8	21.1	88.0
Ferrous	11.6	15.2	14.5	13.8	1.2	1.8	1.3	1.4	15.2	63.3
Ferric	7.8	4.5	7.2	6.5	1.3	1.3	1.2	1.3	7.8	32.5

(See Fig. 4.)

Blank No. Phos.	Acid Phos.	Rock Phos.	Tricalcium Phos.	Aluminum Phos.	Ferrous Phos.	Ferric Phos.

FIG. 1.—THE GROWTH OF OATS IN QUARTZ CULTURES WITH PHOSPHATES INDICATED

In quartz cultures oats has weak feeding powers for rock phosphate, but utilizes the other forms of phosphates uniformly well.

Blank No. Phos.	Acid Phos.	Rock Phos.	Tricalcium Phos.	Aluminum Phos.	Ferrous Phos.	Ferric Phos.

FIG. 2.—THE GROWTH OF CORN IN QUARTZ CULTURES WITH PHOSPHATES INDICATED

Corn like oats in quartz cultures has weak feeding powers for rock phosphate, but unlike oats it does not utilize iron phosphates as well.

Blank No. Phos.	Acid Phos.	Rock Phos.	Tricalcium Phos.	Aluminum Phos.	Ferrous Phos.	Ferric Phos.

FIG. 3.—THE GROWTH OF RAPE IN QUARTZ CULTURES WITH PHOSPHATES INDICATED

In quartz cultures rape has strong feeding powers for rock phosphate, but does not utilize ferric phosphate as well as many other plants.

TABLE VI.—AIR-DRY WEIGHTS IN GRAMS OF BARLEY PRODUCED WITH PHOSPHATES INDICATED

Kind of phosphate	Tops				Roots				Average weight of total crop	Per cent of standard
	A	B	C	Av.	A	B	C	Av.		
Acid	17.50	15.40	15.60	16.17	5.40	4.10	4.10	4.53	20.70	100.0
Aluminum	16.90	17.00	15.70	16.53	5.40	5.35	4.70	5.15	21.68	104.7
Tricalcium	10.85	9.45	7.40	9.23	4.50	3.45	3.00	3.65	12.88	62.2
Ferric	22.00	20.10	21.30	21.13	7.20	5.45	6.90	6.52	27.65	133.5
Ferrous	11.85	12.65	12.05	12.18	4.85	4.35	3.80	4.33	16.51	79.7
Magnesium	2.30	3.60		2.90	.20	.40		.30	3.20	15.5
Manganous	20.30	21.60	20.75	20.88	6.05	4.55	4.60	5.07	25.95	125.3
Rock	3.10	3.30	3.30	3.23	2.45	1.70	2.20	2.12	5.35	25.8
Blank	1.70	1.85	2.05	1.87	1.50	1.70	1.60	1.60	3.47	16.7

See Fig. 5.)

TABLE VII.—AIR-DRY WEIGHTS IN GRAMS OF CLOVER PRODUCED WITH PHOSPHATES INDICATED

Kind of phosphate	Tops			Average	Per cent of standard
	A	B	C		
Acid	11.15	10.00	8.95	10.03	100.0
Aluminum	8.50	9.05	7.80	8.45	84.2
Tricalcium	6.60	6.80	6.00	6.47	64.5
Ferric	7.90	7.40	5.45	6.92	68.9
Ferrous	2.15	3.40	1.55	2.37	23.6
Magnesium	1.80	3.50	2.75	2.68	26.7
Manganous	.20	.70	.40	.43	4.2
Rock	.70	.55	.60	.62	6.1
Blank	.10	.10	.10	.10	1.0

Blank No. Phos. | Acid Phos. | Rock Phos. | Tricalcium Phos. | Aluminum Phos. | Ferrous Phos. | Ferric Phos.

FIG. 4.—THE GROWTH OF BUCKWHEAT IN QUARTZ CULTURES WITH PHOSPHATES INDICATED

In quartz cultures, buckwheat feeds strongly on rock phosphate, and also utilizes the other forms of phosphates uniformly well.

Acid | Aluminum Phos | Tricalcium Phos. | Ferric Phos. | Ferrous Phos. | Magnesium Phos. | Manganous Phos. | Rock Phos. | Blank No Phos.

FIG. 5.—THE GROWTH OF BARLEY IN QUARTZ CULTURES WITH PHOSPHATES INDICATED

rt cultures barley feeds a little more strongly than oats on rock phosphate. Barley grows exceptionally well on ferric phosphate.

Rock Phos. | Acid Phos. | Rock Phos. | Acid Phos. | Rock Phos. | Acid Phos. | Rock Phos. | Acid Phos.

Corn | Oats | Rape | Buckwheat

FIG. 6.—THE COMPARATIVE GROWTH OF SEVERAL PLANTS ON ROCK PHOSPHATE AND ACID PHOSPHATE IN QUARTZ CULTURES

This shows the weak feeding powers of corn and oats on rock phosphate in quartz cultures compared to the strong feeding powers of rape and buckwheat.

TABLE VIII.—AIR-DRY WEIGHTS IN GRAMS OF SERRADELLA PRODUCED WITH PHOSPHATES INDICATED

Kind of phosphate	Tops			Average	Per cent of standard
	A	B	C		
Acid	7.35	8.45	7.50	7.77	100.0
Aluminum	7.65	4.05	6.65	6.12	86.7
Tricalcium	7.50	7.55	6.90	7.02	90.4
Ferric	9.80	6.55	9.70	8.68	111.7
Ferrous	2.50	2.35	1.70	2.18	28.2
Magnesium	3.55	3.10	5.00	3.88	49.9
Manganous	3.60	4.25	4.20	4.02	51.7
Rock	.35	.20	.20	.25	3.2
Blank	.05	.05	.05	.05	.6

TABLE IX.—AIR-DRY WEIGHTS IN GRAMS OF MILLET PRODUCED WITH PHOSPHATES INDICATED

Kind of phosphate	Tops			Average	Per cent of standard
	A	B	C		
Acid	21.15	18.65		19.90	100.0
Aluminum	18.05	17.95	15.80	17.27	86.7
Tricalcium	7.90	7.80	5.20	6.93	34.8
Ferric	21.20	22.10	18.70	20.67	103.8
Ferrous	6.35	6.40	5.80	6.18	31.0
Magnesium	1.80		4.60	3.20	16.0
Manganous	15.50	14.30	14.30	14.70	73.8
Rock	.90	.70	.85	.82	4.1
Blank	.15	.15	0.15	0.15	0.7

TABLE X.—AIR-DRY WEIGHTS IN GRAMS OF ALFALFA PRODUCED WITH PHOSPHATES INDICATED

Kind of phosphate	Tops			Average	Per cent of standard
	A	B	C		
Acid	6.55	6.80	5.60	6.32	100.0
Aluminum	5.25	4.95	4.70	4.97	78.6
Tricalcium	8.50	5.80	4.50	6.27	99.2
Ferric	4.30	6.25	7.20	5.92	93.6
Ferrous	2.20	1.55	1.60	1.78	28.1
Magnesium	.30	.60		.45	7.1
Manganous	1.50	1.30	1.15	1.32	20.8
Rock	3.20	1.00	3.05	2.42	38.3
Blank	.10	.10	.10	.10	1.5

Ferric Phos. | Rock Phos. | Acid Phos. | Ferric Phos. | Rock Phos. | Acid Phos.

FIG. 7.—THE UTILIZATION OF ROCK PHOSPHATE AND FERRIC PHOSPHATE BY RAPE AND OATS IN QUARTZ CULTURES

Striking differences in plant characteristics of oats and rape are indicated in the utilization of ferric and rock phosphate.

Table XI.—Air-Dry Weights in Grams of Corn Produced with Phosphates Indicated (Second set)

Kind of phosphate	Tops				Roots				Average weight of total crop	Per cent of standard
	A	B	C	Av.	A	B	C	Av.		
Acid	43.20	40.00	41.55	41.58	15.80	11.90	15.00	14.23	55.81	100.0
Aluminum	22.65	21.00	24.35	22.66	9.30	7.85	9.10	8.75	31.41	56.3
Tricalcium	9.15	12.60	10.65	10.80	4.10	4.50	4.10	4.23	15.03	26.8
Ferric	16.05	14.55	17.55	16.05	7.25	5.30	6.70	6.42	22.47	40.3
Ferrous	7.25	7.30	7.35	7.30	3.55	3.45	3.45	3.48	10.78	19.3
Magnesium	11.10	7.10	9.70	9.30	3.15	1.70	2.85	2.57	11.87	21.3
Manganous	31.20	30.30	33.25	31.58	12.65	10.35	10.25	11.08	42.66	76.4
Rock	3.25	3.20	4.00	3.48	2.00	2.10	2.20	2.10	5.58	10.0
Blank	3.05	3.15	2.55	2.92	1.90	2.15	1.60	1.88	4.80	8.6

Table XII.—Summary of Tables II to XI Inclusive. Per cent Normal Growth of Various Plants on Phosphates Indicated when Growth on Acid Phosphate is taken as Normal and Represented by 100

Kind of plant	Kind of Phosphate								
	Blank	Acid	Aluminum	Tricalcium	Ferric	Ferrous	Rock	Magnesium	Manganous
Oats	6.8	100.0	96.4	70.5	79.9	82.9	9.1		
Buckwheat	3.6	100.0	88.0	70.1	32.5	63.3	70.0		
Rape	0.8	100.0	96.4	76.2	23.4	61.5	46.8		
Corn	8.6	100.0	56.3	26.8	40.3	19.3	10.0	21.3	76.4
Barley	16.7	100.0	104.7	62.2	133.5	79.7	25.8	15.5	125.3
Alfalfa	1.5	100.0	78.6	99.2	93.6	28.1	38.3	7.1	20.8
Clover	1.0	100.0	84.2	64.5	68.9	23.6	6.1	26.7	4.2
Millet	0.7	100.0	86.7	34.8	103.8	31.0	4.1	16.0	73.8
Serradella	0.6	100.0	78.7	90.4	111.7	28.2	3.2	49.9	51.7

Discussion of Results in Tables II to XII Inclusive on the Utilization of Different Phosphates by Various Plants

The data in Tables II to XIII inclusive, together with figures show that the plants made very little growth on the blank cultures which received all nutrients except phosphates, and also that the plants made normal or good growths on the cultures that received the nutrients with the soluble acid phosphate. This indicates that the conditions were properly controlled for the purposes of the investigation under discussion.

The summary of Tables II to XI inclusive as given in Table XII, is a fair and concise presentation of the data in those tables. In this summary the cultures which received the soluble acid phosphate are taken as the standards or normal cultures and are represented by 100. The others are represented by a proportionate number.

The use of the blank as a standard taken at 100, and representation of others by a proportionate number, as has been done by some investigators, is objectionable in work of this nature, since it may lead to numbers which are very

misleading; e.g., if the data in Tables IV and V on the growth of rape and buckwheat on rock phosphate were represented in this way, there would be obtained for rape a figure of 5900 and for buckwheat a figure of 1866 indicating that rape grew much better on rock phosphate than buckwheat, while in fact the buckwheat made a more nearly normal growth under those conditions than did the rape. Many other cases of this kind can be found.

The use of a number which represents the per cent increase over the blank, is also objectionable in work of this kind. Chirikov[28] in representing some of Prianischnikov's data in this manner obtains the number 2789 for rape and 1477 for buckwheat, while the actual data of weights show that the buckwheat did as well on rock phosphate as on acid phosphate, and the rape made only about one-half as much growth on the rock phosphate as on the acid phosphate.

Blank cultures in which one or more of the essential elements are entirely missing are not fair bases or standards on which to base comparative growths and feeding powers of plants, for reasons as follows: The amount of the missing element carried by the seeds of the different plants in question may vary greatly and hence influence the results. The requirements of the different plants for the missing element may also be very different and hence greatly influence the weight of the crop on the blank. Since the weights of the blanks are usually small, slight differences in these weights give rise to a large difference in the comparative figures obtained by using the blanks as a standard. The use of a normal culture instead of a blank, as a standard is thus much more desirable. Possibly figures representing actual or comparative amounts of phosphorus taken up by the different plants would be still more preferable as an indication of the feeding powers of the plants.

Reference to Table XII shows that all the plants utilized the phosphorus of aluminum phosphate to a considerable degree. With the exception of acid phosphate, the aluminum phosphate gave the most uniformly good results. The tricalcium phosphate and ferric phosphate were also utilized to a fair degree. In the utilization of these two phosphates the various plants exhibited considerable differences.

[28] Russ. Jour. Expt. Landw. 15 (1914) 54.

The barley made an exceptionally vigorous growth on the ferric phosphate, growing even better than on the soluble acid phosphate. This difference in vigor and growth was noticeable a week after the plants had come up. The rape made a comparatively poor growth on the ferric phosphate. The ferrous phosphate in most cases was not utilized nearly as well as the ferric phosphate, although some of the plants utilized it to a considerable degree.

The various plants showed striking differences in their powers to utilize the phosphorus of rock phosphate. Some of the plants appeared to have little power of obtaining phosphorus from this source, while rape and buckwheat exhibited considerable power.

None of the plants grew well on the magnesium phosphate, although some made a considerable growth. Undoubtedly, because of the considerable solubility of the magnesium phosphate due to hydrolysis,[29] the toxic effect of an unfavorable ratio of soluble magnesia inhibited the growths rather than an insufficient supply of phosphorus in a soluble form. The abnormal appearance of leaves and roots in most cases seemed to substantiate this.

The manganous phosphate gave peculiar results. The barley made a very heavy growth on this phosphate, but the plants did not show the great vigor and health as in the case of the ferric phosphate. Determination made over a period of two weeks showed that the transpiration of water by barley growing on manganous phosphate was greater than in the case of the ferric phosphate, although the growth in the latter case was the greatest of all. The manganese undoubtedly caused physiological disturbances in the plants. In all cases and especially with alfalfa and clover, the chlorophyll of the leaves was affected as shown by yellow spots. This was especially noticeable during the early stages of growth. The effect of manganese compounds on the chlorophyll has been observed by a number of investigators.[30] The roots of the corn and barley were colored brown in the manganous phosphate cultures, but otherwise appeared normal.

The great differences exhibited by the various plants in their growths on the different phosphates indicate that plant

[29] U. S. Dept. Agr., Bur. Plant Ind., Bul. 45, p. 56.
[30] Loew, Aso and Sawa, U. S. Dept. Agr., Bur. Plant Ind. Bul. 45, p. 23.

characteristics play an important role in this connection. The fact that rape made a better growth on rock phosphate than on ferric phosphate, while in the case of oats the opposite was true, (see Fig. 7) indicates that solubility alone is not the only factor involved in the utilization of these phosphates by plants. The remarkably vigorous growth of the barley with ferric phosphate is another indication that aside from solubility or availability, some phosphates seem to serve the needs of certain plants better than others. The remarkable adaptability of certain soils to certain crops may be partly due to causes of this nature.

THE AVAILABILITY OF FERRIC AND ALUMINUM PHOSPHATES

The rather high availability of the precipitated ferric and aluminum phosphates, as indicated by the present investigation as well as by previous investigators, is satisfactorily explained as being due to a hydrolysis reaction which may be represented as follows:

$$xFePO_4 + 3H_2O \rightleftarrows H_3PO_4 + Fe(OH)_3.(x-1)\ FePO_4$$

A similar reaction may be assumed for aluminum phosphate. The investigations of Lachowicz, Cameron,[31] Bell, and others, show that a liter of pure water acting on a precipitated phosphate of either iron or aluminum may bring into solution by hydrolysis from several milligrams up to a tenth of a gram and even more, of phosphoric acid. The addition of carbonic acid to the water has little effect on the solubility of these phosphates for the reason that ferric and aluminum carbonates are not formed under ordinary conditions. In this reaction with water the acidic part goes into solution in much greater proportion than the basic part which is practically insoluble, and hence the residue becomes basic. The concentration of phosphoric acid in solution naturally increases as the ratio of phosphate used to water increases.

As already stated, Schloesing[32] and Kossowitsch[33] showed that plants could obtain their supply of phosphorus from solutions containing only one to two milligrams of phosphoric anhydride per liter. The hydrolysis reaction is thus

[31] For detailed references see U. S. Dept. Agr., Bur. Soils, Bul. 41 by Cameron and Bell.
[32] Loc. Cit.
[33] Loc. Cit.

ample explanation of how plants are able to secure their supply of phosphorus from freshly precipitated phosphates of iron and aluminum.

The hydrolysis reaction just given for ferric phosphate represents the first step in the action of the water on a mass of the phosphate. If the phosphoric acid made soluble is removed by precipitation, moving water or plant roots, then the reaction continues further resulting in the original phosphate becoming more and more basic. As the resulting phosphate becomes more and more basic, the availability or solubility by further hydrolysis of the phosphoric acid remaining therein undoubtedly also becomes less and less, and hence its value as a source of phosphorus for plants also becomes lowered. That conditions of this kind actually arise at least in the case of ferric phosphate is supported by the results of Nagaoka, given in Table I. These results show that freshly precipitated ferric phosphate, when aplied to a soil, acted as an excellent source of phosphorus the first year, standing first in comparison to the others tried, but to succeeding crops it acted less favorably, standing in fourth place the fourth year.

The favorable results secured in quartz cultures with freshly precipitated ferric and aluminum phosphates are thus satisfactorily explained by the hydrolysis of the phosphate, which if comparatively fresh allows the formation of a solution sufficiently concentrated in phosphoric acid to meet the needs of growing plants. Under soil conditions, in which case the hydrolysis continues from year to year, there probably results finally, a phosphate which is so basic that the *rate* of solution and final concentration of phosphoric acid are too low to meet the maximum needs of growing plants. The low availability of the phosphates in some soils which presumably have their phosphorus largely in the form of iron and aluminum phosphates is thus also explained.

In soils other factors which greatly lower the availability of the phosphorus in iron and aluminum phosphate may also be at work. As indicated by the work of Peterson[34] these phosphates may form comparatively insoluble complexes with organic matter. It seems possible that basic

[34] Wis. Agr. Expt. Sta., Research Bul. 19.

phosphates may combine with acidic humic compounds or possibly even acid silicates and form very resistant and insoluble compounds. The physical as well as the chemical nature of these complexes may be such as to greatly lower the solvent action of the soil solution in making the phosphorus therein available to growing plants.

THE AVAILIBILITY OF TRICALCIUM AND TRIMAGNESIUM PHOSPHATES

The availability of the triphosphates of calcium and magnesium is also brought about partly by hydrolysis.[35] The great difference however, compared to ferric and aluminum phosphates, is that in the case of calcium and magnesium phosphates the basic part on hydrolysis forms a soluble hydroxide which may be removed by plants or the drainage water. Although the acidic part of these phosphates may go into solution a little more rapidly than the basic part, yet the rate at which these phosphates change to basic phosphates is much slower than in the case of ferric and aluminum phosphates. The solubility of the phosphates of calcium and magnesium thus does not decrease nearly as rapidly since their composition remains more uniform. The great demand in the soils of the humid region for bases of lime and magnesia undoubtedly aids greatly in preventing the formation of phosphates of these bases which are so basic as to be insufficiently available to plants. Since carbonic acid forms soluble bicarbonates of calcium and magnesium, it aids greatly in the solution of these phosphates and the prevention of the formation of excessively basic phosphates.

The great possible advantage of keeping the phosphates of the soil largely in the form of calcium phosphate instead of ferric and aluminum phosphate is thus perhaps partially explained in the discussions given. Soils well supplied with limestone are proverbially fertile. Hilgard[36] states: "In the presence of high lime percentages, relatively low percentages of phosphoric acid and potash may nevertheless prove adequate; while the same, or even higher amounts in the absence of satisfactory lime percentages prove insufficient for good

[35] For details and references see U. S. Dept. Agr., Bur. Soils, Bul. 41.
[36] "Soils," p. 365.

production." On the same page, Hilgard states further in a footnote as follows: "This statement appears contradictory of the observations of Schloesing fils, upon the solubility of phosphoric acid in presence of lime carbonate (Ann. Sci. Agron., tome 1, 1899) but the natural conditions seem to justify fully the above conclusion."

Reference to this work of Schloesing shows that even in the presence of considerable calcium carbonate, carbonated water dissolves over a milligram of phosphoric acid per liter. As already indicated this is perhaps sufficient concentration to meet the needs of growing plants, provided the *rate* of solution is rapid enough to maintain this concentration in the local areas in contact with the root hairs, where the phosphates are actively taken up by the plant. In the soil the reaction is probably greatly aided due to the fact that the soluble calcium bicarbonate is removed by the feeding plants, the soil acids, and the drainage water.

In pot cultures with acid soils needing phosphate fertilization the writer has often observed a decrease in the growth of cereals due to the addition of lime carbonate. This decrease in availability is undoubtedly due to a condition which is temporary. In becoming acid a soil goes into a condition which takes years to develop, and the addition of lime carbonate causes many profound changes, some of which may affect the availability of the phosphorus. The very favorable results obtained by investigators in long continued field experiments involving the use of ground limestone is strong evidence that any unfavorable result at the start is due to temporary conditions.

The Feeding Power of Plants

As stated on page 11 it was found that plants with a high calcium oxide content are strong feeders on rock phosphate. In first applying this principle several cases were found which appeared to be exceptions: viz., alfalfa, clover, tobacco and serradella.[37] It is to be noticed that these are all plants with very small seeds. It was thus thought possible that the apparently weak feeding powers exhibited by these plants in quartz cultures was due to the fact that the seeds,

[37] For tobacco see Prianischnikov, Land. Vers. Sta., 65 (1907) 27. For others see Table XII.

being small, did not furnish sufficient phosphorus to produce plants of adequate size in the usual time, to indicate their true feeding power. As is evident a plant must be of reasonable size and possess a fair root system before it can be expected to show the true feeding power of the species in question. The four plants mentioned all grow slowly at the start, even if sufficient soluble plant food is at hand.

In order to test the question regarding these plants, further experiments were carried out, the results of which are reported in Table XIII. These experiments were conducted

TABLE XIII.—AIR-DRY WEIGHTS IN GRAMS OF CROPS PRODUCED WITH TREATMENTS OF PHOSPHATES AND NUTRIENT SOLUTION WITH AND WITHOUT SOLUBLE CALCIUM SALT AS INDICATED

Kind plant	No phosphate but with soluble calcium salt	Acid phosphate with soluble calcium salt			Rock phosphate with soluble calcium salt			Rock phosphate without soluble calcium salt		
		A	B	Av.	A	B	Av.	A	B	Av.
Corn	4.00	16.0	18.2	17.10	4.7	4.9	4.80	5.7	4.8	5.25
Millet	.20	15.6	16.0	15.80	1.3	1.3	1.30	1.4	1.4	1.40
Turnip	.05	6.3	7.0	6.65	3.6		3.60	4.4	4.6	4.5
Sunflower	.35	12.5	14.5	13.50	5.3	5.5	5.40	2.0	2.6	2,30
Tobacco	.10	11.4	11.5	11.45	6.9		6.90	7.6	7.2	7.40
Alfalfa 1 crop	No growth	1.3	1.4	1.35	1.?	1.0	1.10	.5	1.1	0.80
Alfalfa 2 crop	No growth	8.4	8.2	8.30	5.0	6.2	5.60	5.2	5.4	5.30
Alfalfa 3 crop	No growth	3.6	4.3	3.95	4.7	5.0	4.85	5.0	5.5	5.35
Alfalfa 4 crop	No growth	6.2	8.4	7.30	8.7	8.4	8.55	8.7	8.6	8.65

(See Figs. 8, 9, 10 and 11)

with quartz cultures in the same general way as the previous ones. As indicated two nutrient solutions, one with, and the other without, soluble calcium salt were used with the rock phosphate treatments. The nutrient solution with soluble calcium salt was the same as that given on page 12. The other without calcium salt was made up as follows, with a minimum of magnesium salts in order to prevent as far as possible the unfavorable effects of a high magnesia ratio:

KNO_3—120 Gms.
$NaNO_3$—60 Gms.
$MgCl_2 \cdot 6H_2O$—1 Gms.
$MgSO_4 \cdot 7H_2O$—5 Gms.
Water 3 liters

Blank No. Phos.	Rock Phos. with soluble calcium salt	Rock Phos. without soluble calcium salt	Acid Phos.

FIG. 8.—THE GROWTH OF TOBACCO IN QUARTZ CULTURES WITH PHOSPHATES AND OTHER TREATMENTS AS INDICATED

Tobacco feeds quite strongly on rock phosphate in quartz cultures. The presence of a soluble calcium salt has little effect on this feeding power.

Blank No Phos.	Rock Phos. with soluble calcium salt	Rock Phos. without soluble calcium salt	Acid Phos.

FIG. 9.—THE GROWTH OF TURNIPS IN QUARTZ CULTURES WITH PHOSPHATES AND OTHER TREATMENTS INDICATED

In quartz cultures turnips feed quite strongly on rock phosphate. The presence of a soluble calcium salt has little effect on this feeding power.

Blank No Phos.	Rock Phos. with soluble calcium salt	Rock Phos. without soluble calcium salt	Acid Phos.

FIG. 10.—THE GROWTH OF SUNFLOWERS IN QUARTZ CULTURES WITH PHSOPHATES AND OTHER TREATMENTS INDICATED

In quartz cultures, the sunflower feeds considerably on rock phosphate. The presence of a soluble calcium salt is beneficial.

Blank No. Phos.	Rock Phos.	Acid Phos.

FIG. 11.—THE GROWTH OF ALFALFA IN QUARTZ CULTURES WITH PHOSPHATES INDICATED

Alfalfa feeds very strongly on rock phosphate.

The tobacco plants were grown on soil until the leaves were about an inch long and then transplanted to the quartz cultures. Several crops of alfalfa were grown.

The results with tobacco and alfalfa show that these plants exhibit strong feeding powers on rock phosphate after they have once developed the necessary feeding machinery. Undoubtedly if tested in this way clover and serradella would give similar results. The experiments of Kossowitsch[38] with soil, and those of Merrill[39] with sand cultures indicate that clover has a strong feeding power for rock phosphate. Of the apparent exceptions noted there remains only serradella which has not been critically tested, and it appears reasonably safe to accept the theory.

In Table XIV are given thirteen species of plants whose feeding powers on rock phosphate have been tested under adequately controlled conditions. Results of some investigators have been purposely omitted since the quartz sand used evidently contained appreciable amounts of phosphorus as indicated by the growths of the blanks. The calcium oxide content of these plants is also given in the table.

TABLE XIV.—PER CENT NORMAL GROWTH ON ROCK PHOSPHATE OF PLANTS INDICATED, AND THEIR CONTENT OF CALCIUM OXIDE *

Kind of plant	Per cent Normal Growth		Calcium oxide in dry material indicated	
	Source of data	Data	Per cent	Material analyzed
Millet	This Pub., Table IX	4.1	0.46	Cut as hay
Rye	Land. Vers. Sta. 56, 122	6.0	0.60	Before bloom
Wheat	Land. Vers. Sta. 56, 117	8.0	0.50	Plants before heading
Oats	This Pub., Table II	9.1	0.52	Plants before heading
Corn	This Pub., Table XI	10.0	0.83	Plants in bloom
Barley	This Pub., Table VI	25.8	0.90	Plants before heading
Rape	This Pub., Table IV	46.8	1.78	Plants in bloom
Peas	Land. Vers. Sta. 56, 123	46.0	1.90	Plants in bloom
Buckwheat	This. Pub., Table V	70.0	3.30	Plants in bloom
Lupines	Land. Vers. Sta. 56, 119	72.5	3.20	Leaves
Alfalfa	This Pub., Table XIII	67.4	3.00	Plants in bloom
Tobacco	This Pub., Table XIII	60.2	3.40	Whole plants 7″ high
Turnip	This Pub., Table XIII	55.8	3.83	Leaves

*The data on calcium oxide content were taken from Wolff's "Aschen Analysen," with the exception of the figure for tobacco, which was obtained by the analysis of the crop given in Table XIII. The references to Land. Vers. Sta., refer to the work of Prianischnikov and his assistants.

[38] Russ. Jr. Expt. Landw., 10 (1909) 839.

[39] Loc. Cit.

In diagram A the relation of growth on rock phosphate to calcium oxide content is represented graphically. From this relation the writer was led to make the following statement:[40] "Plants containing a relatively high calcium oxide content have a relatively high feeding power for the phosphorus in raw rock phosphate. For plants containing a relatively low calcium oxide content the converse of the

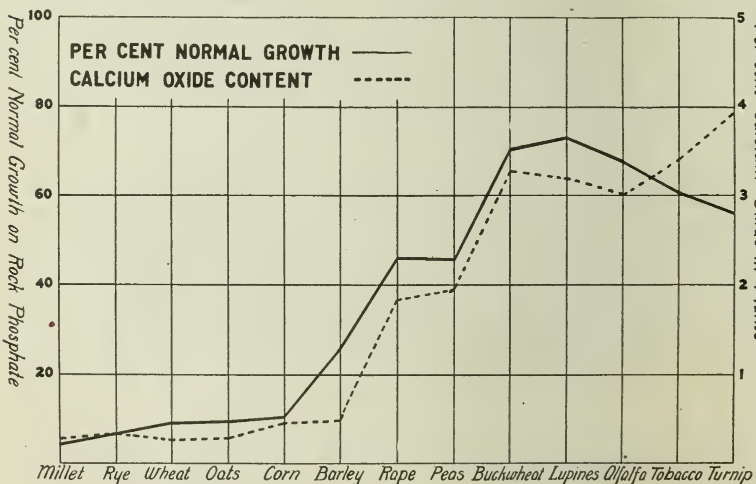

DIAGRAM A.—THE RELATION OF CALCIUM OXIDE CONTENT OF PLANTS TO THE PER CENT NORMAL GROWTH OR FEEDING POWER ON ROCK PHOSPHATE

The diagram shows that the feeding power of a plant for rock phosphate in quartz cultures is closely related with its calcium oxide content. Plants high in calcium oxide are strong feeders on rock phosphate.

above is true. A calcium oxide content of somewhat more than one per cent may be considered relatively high, and less than one per cent relatively low.

"The explanation of the above relation is made possible by means of the laws of mass action and chemical equilibrium. The reaction making the phosphorus in raw rock phosphate available to plants is largely one between carbonic acid and the tricalcium phosphate in the rock phosphate, which may be represented as follows:

$$Ca_3(PO_4)_2 + 2H_2CO_3 \rightleftarrows Ca_2H_2(PO_4)_2 + CaH_2(CO_3)_2.$$

"As is well known if none of the products to the right of the reaction are removed from solution, the reaction soon

[40] Science 41 (1915) 616.

reaches a state of equilibrium. If the dicalcium phosphate is continually removed but the calicum bicarbonate only in part, then the reaction will continue a little farther, but also soon comes to a state of equilibrium due to the accumulation of the calcium bicarbonate. When this point is reached, the further solution of the phosphate is prevented. This is the condition that obtains for such plants as are low in calcium oxide and hence do not absorb the calcium bicarbonate in the proportion to the dicalcium phosphate as given in the reaction. In such cases, the plants soon suffer for soluble phosphates. If both of the products to the right of the reaction are simultaneously and continually removed in the proportion given, then the reaction continues from left to right and there results a continuous supply of soluble phosphates along with soluble calcium bicarbonate. This is the condition that obtains, at least in part, with plants containing a high calcium oxide content, and hence such plants are strong feeders on raw rock phosphate."

The lime needs of plants.—There arises in this connection the question: Why do some plants take up these proportionately large amounts of calcium oxide? The explanation of this may possibly be as follows: Plants with a high calcium oxide content usually have a high protein content. In protein synthesis, calcium oxide may be required for several purposes, one of which may be the neutralization of acids which are formed.

Oxalic acid, a poisonous substance, is usually found among the plant acids, and is held by some to be a by-product of protein synthesis.[41] It may thus be argued, that in order to largely neutralize this acid and perhaps others and form insoluble or neutral harmless substances, the plant requires calcium carbonate. The insoluble calcium oxalate and other calcium salts would thus accumulate in the plant and together with the calcium that may possibly enter into combination with proteins or other plant substances give rise to the high calcium oxide content which in turn makes possible the strong feeding power for rock phosphate.

This explanation also offers an explanation why most legumes growing on acid soils are benefited by liming. Except in unusual cases the injury resulting from soil acidity

[41] U. S. Dept. Agr., Bur. Plant Ind., Bul. 45 (1903) 41; Duggar, Plant Physiology, p. 177; Berthelot and André, Compt. rendus, 102 (1886) 995 and 1043.

is probably not due to the direct corrosive action of the soil acids on the roots of the legumes or on the cell material of the legume bacteria, but to the conditions which accompany soil acidity. When not disturbed, the soil solution comes to a state of equilibrium with the phosphates, silicates, carbonates, organic compounds and other solid compounds. In case a soil is acid, then solid carbonates in appreciable amounts are usually absent. Hydrolysis and carbonation are the principal processes that bring dissolved substances into the soil solution.

The equilibrium conditions between the carbonic acid in the soil solution and the solid insoluble soil acids and soil silicates may be taken to illustrate the point under discussion. The insoluble soil acids of the acid soil, may be represented by H_2X, and $CaSiO_3$ may be taken as a representative silicate. In this system of soil acids, silicate and carbonic acid, the following reactions are possible:

$$(1)\quad CaSiO_3 + 2H_2CO_3 \rightleftharpoons H_2SiO_3 + CaH_2(CO_3)_2$$
$$(2)\quad CaSiO_3 + H_2X \rightleftharpoons H_2SiO_3 + CaX$$
$$(3)\quad CaH_2(CO_3)_2 + H_2X \rightleftharpoons 2H_2CO_3 + CaX$$

As is evident from these reactions, the concentration of calcium bicarbonate in solution at equilibrium will depend upon, besides the concentration of carbonic acid and temperature, the amount of surface exposed by the calcium silicate and especially upon the amount and strength of soil acids present causing soil acidity. If considerable amounts of relatively strong soil acids are present then the concentration and *rate of formation and solution* of calcium bicarbonate and delivery to the plant will be too low to meet the maximum need of growing alfalfa and hence the growth of the plant will be checked.

Insufficient supply of calcium bicarbonte to neutralize the oxalic acid and other acids which are formed may thus check the protein synthesis and even affect the protein content of the plant. Here, as in all cases, in order for the reactions involved in protein synthesis to continue, the products (one of which may be oxalic acid) must be removed or precipitated in an insoluble or harmless form. It is possible that in nitrogen fixation by the legume bacteria, acids, possibly oxalic, are formed which, together with those

formed directly by the plant's metabolism, must be neutralized lest they act injuriously on the legume bacteria. It is also possible that in order for the nitrogen fixation in the nodules to continue at a maximum rate, the nitrogen fixed must be largely removed by the plant and built into plant proteins, a process only possible at maximum rate when the supply of calcium bicarbonate is adequate. The compounds of nitrogen arising from the fixation of nitrogen in the nodules may possibly be looked at as by-products of bacterial activity which must be removed if the process is to continue.

The stronger that the acids of acid soils are, that is, the greater the avidity, the lower will be the concentration of calcium bicarbonate and the slower will be the rate of delivery of this calcium bicarbonate to the plant. Since red clover is lower in protein and calcium oxide than alfalfa and perhaps also grows slower, the explanation given also offers a possible explanation why red clover can withstand a higher degree of acidity than alfalfa.

Soils which are not acid and contain considerable solid calcium carbonate give rise to a soil solution saturated with calcium bicarbonate. In such cases the rate of delivery of calcium bicarbonate to growing plants is sufficient for the needs of all plants.

If the function of the calcium carbonate and bicarbonate is as just indicated, then it is evident that the addition of calcium chloride or sulphate to the nutrient solution should have little effect on the feeding powers of plants for rock phosphate, since the chloride or sulphate cannot function as the carbonate in making oxalic acid or other acids innocuous. Whether or not calcium chloride or sulphate is present, the need of the carbonate remains. The data in Table XIII bear out this contention. Most of the plants gave a slightly better growth in the absence of calcium chloride but the differences are uniformly small. They indicate that plants use small amounts of calcium for other purposes than neutralization and precipitation of acids, in which case other salts serve as well as the carbonates.

The presence of the calcium ion due to the addition of calcium chloride has a depressing effect on the solubility of tricalcium phosphate as indicated by the work of Cameron and Hurst.[42] This depressing effect would, however, be

[42] U. S. Dept. Agr., Bur. Soils, Bul. 41 (1907) 33.

very small with concentrations of calcium chloride used in nutrient solutions, and hence influences from this on the feeding power for rock phosphate should be small.

One of the plants, the sunflower, grew much better on rock phosphate in the presence of calcium chloride than in the absence. This may be due to a more favorable ratio of calcium to magnesium brought about by the addition of the calcium chloride. It is also possible that the sunflower plant requires considerable amounts of soluble calcium salts for other purposes than neutralization, in which case the calcium chloride serves the purpose.

Chirikov[43] reports that in the absence of soluble calcium salts barley makes considerable use of the phosphorite. It is to be noted that the total growths reported by Chirikov are quite small in all cases. In a test made with barley and with most of the plants indicated in Table XIII only a slight increase in growth was observed when soluble calcium salts were omitted. Chirikov also states in his report that it is not the calcium oxide and phosphoric acid content but the ratio of calcium oxide to phosphoric anhydride, which is the important thing to consider in this connection. Since both the calcium oxide and phosphoric anhydride content of a plant may vary considerably depending upon the conditions of growth it is evident that the ratio of the two may vary more than either of the two singly. The writer thus believes that the calcium oxide content itself is the better index of the feeding power. The close relation indicated in diagram A, substantiates this contention.

Chirikov in his report notes a considerable number of exceptions to the theory as presented. It is important to note that much of the data of cultural experiments which he has used is probably not adapted to this purpose, since many of the blanks show very considerable growths.

The writer believes that, in the case of plants which form a heavy woody stalk like the lupine, or a fleshy root like the turnip which simply acts as a storehouse, the calcium oxide content of the leaves should be considered and not that of the whole plant. It is in the leaves that the most active life processes take place and where the calcium carbonate is largely needed and deposited. Considerable

[43] Loc. Cit.

amounts may be washed away by rain as shown by the work of Le Clerc and Breazeale.[44] However, plants which take up large amounts undoubtedly retain relatively large amounts after the losses have taken place.

It seems probable that when more plants have been critically tested, exceptions to the rule may be found in the case of plants which make peculiar growths, or perhaps use large amounts of calcium oxide for other purposes than neutralization of acids in the plant sap. It should be noted in this connection that even young plants of the graminae when grown in the greenhouse may contain slightly more than one per cent of calcium oxide, due perhaps to the fact that little is lost by washing. Under most greenhouse conditions, all plants contain relatively more salts.

Feeding power of plants under soil conditions.—Under natural soil conditions different results than those obtained with quart cultures are to be expected in many cases in the utilization of rock phosphate, especially by plants which have weak feeding powers in quartz cultures. Under these conditions the calcium bicarbonate, if not taken up by the plant, may be removed in the drainage water or if the soil is acid may be taken up by the soil acids. The work of Prianischnikov and Kossowitsch with acid soils, reviewed on pages 4 and 5 shows this to be true. Even under these conditions, with the plants they tried, those having strong feeding powers in quartz cultures also exhibited the strongest feeding powers for rock phosphate in acid soil cultures.

As indicated by the work of Kossowitsch (see page 7) the relative feeding powers of plants for the phosphorus naturally present in the soil may be entirely different than that for rock phosphate. In the utilization of ferric phosphate as indicated in Table XII this is further emphasized. In the utilization of soil phosphates, especially if the phosphates are largely in the form of ferric and aluminum phosphates, extent and character of root systems of the plants in question are probably very important factors, since these phosphates go into solution largely by hydrolysis, and the rate at which a plant may utilize the phosphorus is

[44] U. S. Dept. Agr., Yearbook (1908) 389.

proportional to the absorbing surface of the roots. In the case of the utilization of rock phosphate, hydrolysis is of minor importance and the action of carbonic acid is of major importance. The effectiveness with which the carbonic acid acts on the rock phosphate is thus of much greater importance than the area of the absorbing surface. Rape and buckwheat with rather limited root systems, but with high calcium oxide contents, are thus strong feeders on rock phosphate. Oats which develops an extensive and very fibrous root system but has a low calcium oxide content thus feeds vigorously on the phosphates naturally present in the soil, but very weakly on rock phosphate in quartz cultures. Timothy with its enormous root system is an exceptionally strong feeder for the phosphorus of soils, even when the soils are quite acid.

The ability of certain plants which are weak feeders on rock phosphate in quartz cultures, to feed strongly on the phosphorus naturally present in soils, especially acid soils, makes possible a rapid early growth and hence a vigorous feeding system. These plants may then feed more vigorously on the rock phosphate that is applied to the soil than plants which are strong feeders for rock phosphate in quartz cultures, but, like some of the cruciferae, are weak feeders for the phosphorus naturally present in acid soils. With quartz cultures, a thorough distribution of the rock phosphate is secured, and hence even the roots of young seedlings come into contact with sufficient phosphates to largely meet their needs providing they can utilize this form of phosphate. Under field conditions as thorough a mechanical distribution is usually not secured.

The results and discussion given indicate as follows: The feeding of the plant takes place largely in local soil areas, that is the portions actually in contact with the root hairs. The rate of diffusion of soluble salts which are not taken up by the plant, away from the feeding area is perhaps quite slow under most conditions.[45] Because of this rather limited area from which the plant may at any one time draw its supply of phosphorus and potassium, *the rate at which these elements go into solution in the local areas is the more important consider-*

[45] Because of the great solubility and considerable diffusibility of the nitrates, the conditions as regards the nitrogen supply are considerably different than with phosphorus and potassium.

ation than the amounts of these elements which may be drawn off from the whole soil mass by one extraction. The area of surface contact between plant roots and phosphates and the continued rate of solution at these points of contact are the determining factors in the adequacy of the supply of phosphorus for the plant. This emphasizes the importance of maintaining a well distributed and adequate total supply of phosphorus as well as keeping this supply in a form that may be sufficiently available to the feeding roots.

When soluble phosphate fertilizers are applied they may go into solution in the soil water, but are undoubtedly soon largely precipitated as tricalcium, iron and aluminum phosphates. Undoubtedly the two great advantages secured in using these soluble phosphate fertilizers are thoroughness of distribution and ease of hydrolysis of newly precipitated phosphates. This explains why the addition of calcium carbonate does not have the marked lowering effect on the availability of the more soluble phosphates, while with rock phosphate there is a decided effect. In this connection see reference to the work of Prianischnikov on page 4.

The discussion just given emphasizes the following in the use of rock phosphate:

1. The mechanical distribution should be as thorough as possible when the material is applied.

2. Chemical distribution should be aided by applying the phosphate several months or better a year in advance of lime if the latter is also to be used, and by maintaining the supply of organic matter which favors further chemical and biological activities that aid greatly in chemical distribution.

THE EFFECT OF FORM OF NITROGEN SALT ON THE AVAILABILITY OF PHOSPHATES

In Table XV are given the results with corn using different salts as the source of nitrogen. The use of calcium nitrate in place of potassium and sodium nitrate had little effect on the results. The favorable effect of ammonium nitrate on the availability of rock phosphate is, however, especially marked. Under this treatment the corn grew normally. This result is similar to that of Prianischnikov and Kossowitsch noted on pages 5 and 7.

TABLE XV.—AIR-DRY WEIGHTS IN GRAMS OF CORN PRODUCED WITH PHOSPHATES AND NITRATES INDICATED. WEIGHTS ARE AVERAGES OF TWO DUPLICATES AND INCLUDE BOTH TOPS AND ROOTS

Kind of phosphate	Solution A Nitrogen as pot. and sod. nitrate	Solution B Nitrogen as calcium nitrate	Solution C Nitrogen as ammonium nitrate
Aluminum	28.47	32.91	26.10
Tricalcium	23.33	23.65	38.38
Ferric	28.39	30.73	10.50
Acid	33.60	36.45	21.33
Raw rock	7.42	6.38	34.37
Blank	5.43	5.08	3.53

(See Fig. 12)

In the light of the theory presented this result may be satisfactorily explained as follows: Calcium bicarbonate being much more soluble in a water solution of ammonium salts[46] than in water alone, it follows that the addition of ammonium salts allows the preceding reaction given on

KNO_3 $NaNO_3$ — NH_4NO_3 (Rock Phos.) | KNO_3 $NaNO_3$ — NH_4NO_3 (Acid Phos.) | KNO_3 $NaNO_3$ — NH_4NO_3 (Ferric Phos.) | KNO_3 $NaNO_3$ — NH_4NO_3 (Aluminum Phos.)

FIG. 12.—THE INFLUENCE OF FORM OF NITROGEN SALT ON THE UTILIZATION OF DIFFERENT PHOSPHATES BY CORN IN QUARTZ CULTURES

When ammonium nitrate is used in place of sodium and potassium nitrate then corn grows nearly as well on rock phosphate as on acid phosphate.

page 32 to continue from left to right to a much greater extent than if water alone is present. The addition of a salt in which the products of the reaction are more soluble has the same effect to a certain extent as is obtained by removing the products of the reaction.

[46] Comey, Dict. of Chem. Solubilities, 83.

The writer believes it entirely possible that the use of ammonium salts may influence the availability in other ways than the one just given.

On page 42, Research Bulletin 20 of this Station, the writer reported results of pot experiments on the growth of corn with rock phosphate. It is important to state that these results were secured with the nitrogen supplied as ammonium nitrate. This accounts for the very favorable growth of the corn on the rock phosphate.

CHEMICAL ANALYSES OF CROPS GROWN ON VARIOUS PHOSPHATES

Some of the crops grown on the various phosphates were analyzed for certain constituents.

The total phosphorus content of plants.—In Table XVI are given the percentages of phosphorus found in the four crops: viz., corn, barley, clover and serradella. In the analysis the finely ground sample was first moistened with a solution containing magnesium nitrate and oxide, and after evaporation the material was burned to an ash in an electric furnace. The phosphorus was then determined by the alkalimetric method after a second precipitation as the ammonium phospho molybdate.

TABLE XVI.—PERCENTAGES OF PHOSPHORUS IN PLANTS GROWN ON THE PHOSPHATES INDICATED*

Phosphate used	Corn			Barley			Clover			Serradella		
	A	B	Av.	A	B	Av.	A	B	Av.	A	B	Av.
Blank	.087	.087	.087	.069	.060	.065	.093	.103	.097	.144	.125	.135
Rock	.088	.087	.088	.073	.078	.076	.146	.128	.137	.139	.142	.141
Ferrous	.124	.097	.111	.129	.129	.129	.175	.176	.176	.226	.246	.236
Tricalcium	.140	.111	.126	.114	.117	.116	.187	.187	.187	.254	.259	.257
Ferric	.105	.095	.100	.221	.219	.220	.188	.174	.181	.305	.301	.303
Aluminum	.139	.136	.138	.262	.229	.246	.230	.200	.215	.362	.352	.357
Acid	.203	.191	.197	.337	.298	.318	.365	.366	.366	.528	.553	.541
Manganous	.195	.189	.192	.351	.322	.337	.468	.493	.482	.525	.533	.529
Magnesium	.539	.591	.565	.836	.808	.822	.602	.609	.606	.600	.548	.574

*These analyses were made on the crops whose weights are given in Tables VI, VII, VIII, and XI. In each case the crops of two closely agreeing duplicate cultures were analyzed separately and results are given separately as (A) and (B).

The data of Table XVI show wide differences in the phosphorus content of each crop when grown on different phosphates. None of the four plants analyzed made much growth on the rock phosphate in the time allowed, and as is to be expected the phosphorus content is low in each case.

The most striking data in this table are the exceptionally high percentages of phosphorus in the plants grown on

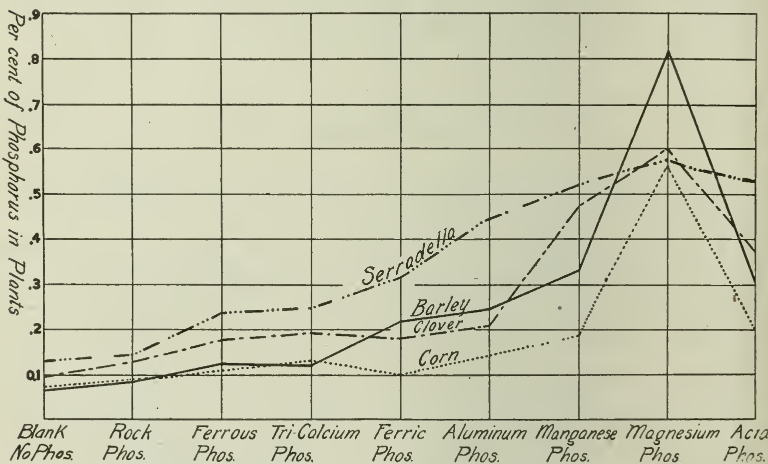

DIAGRAM B.—THE INFLUENCE OF FORM OF PHOSPHATE USED IN QUARTZ CULTURES ON THE PHOSPHORUS CONTENT OF CORN, CLOVER, BARLEY, AND SERRADELLA

The form of phosphate has a marked influence on the phosphorus content of the plants. In every case plants grown on magnesium phosphate had the highest phosphorus content, indicating that magnesium may function in the plant as a carrier of phosphorus.

magnesium phosphate. With all four crops the percentages of phosphorus are highest in this case. Diagram B brings this out graphically in a striking way. It may be argued that the reason for these high contents of phosphorus with magnesium phosphate is that the plants were stunted by the unfavorable effects of the excess of magnesia and at the same time were furnished with an abundance of soluble phosphate. This has probably been a factor in causing these results, but that it has not been the only factor is indicated by the following: The corn, clover and serradella made heavier growths on the magnesium phosphate than on the ferrous phosphate. The clover made a much heavier growth on the magnesium phosphate than on the manganous phosphate. The serradella made practically as good growth

on the magnesium phosphate as on the manganous phosphate.

A possible explanation of a factor which has caused these high contents of phosphorus is the following: Loew[47] holds that the chief function of magnesium is the conveyance of phosphorus in the form of magnesium phosphate to the places of assimilation. The magnesium phosphate being readily hydrolizable, gives up its phosphoric acid for assimilation at the seat of protein synthesis very readily and in a way largely impossible with other phosphates. If Loew's hypothesis is correct, then it would seem reasonable to believe that when the phosphorus is supplied as magnesium phosphate, the best possible conditions for this assimilation are supplied. As a result it is possible that more proteins or organic substances of high phosphorus content are formed than would otherwise be the case. These results thus support Loew's hypothesis as to the function of magnesium.

The contents of organic and inorganic phosphorus and also of nitrogen in corn plants.—In Table XVII

TABLE XVII.—PERCENTAGE CONTENTS OF CORN PLANTS IN CONSTITUENTS INDICATED WHEN GROWN WITH DIFFERENT PHOSPHATE TREATMENTS

Kind of phosphate treatment	Total phosphorus	Inorganic phosphorus			Organic phosphorus	Nitrogen			Crude protein
		A	B	AV.		A	B	AV.	
Acid	0.197	0.100	0.090	0.095	0.102	1.647	1.607	1.627	10.17
Ferric	0.100	0.057	0.051	0.054	0.046	2.182	1.928	2.060	12.88
Magnesium	0.565	0.202	0.207	0.205	0.360	2.819	2.794	2.807	17.54
Tricalcium	......	......	......	......	......	2.182	2.175	2.179	13.62

are given the contents of organic and inorganic phosphorus and of nitrogen in the corn plants grown on the phosphates indicated. The inorganic phosphorus was determined according to the method outlined by Collison,[48] and the organic phosphorus calculated by difference between total and inorganic. The nitrogen was determined by the usual Kjeldahl method. As indicated by the data a larger proportion of the phosphorus in the case of magnesium phos-

[47] U. S. Dept. Agr., Bur. Plant Ind., Bul. 45, 55.
[48] Jr. Ind. Eng. Chem. 4 (1912) 606.

phate was in organic combination than with the other phosphates. The content of nitrogen and hence crude protein was also the highest in the case of magnesium phosphate. This data in Table XVII lends further support to the previously mentioned function of magnesium. The data, however, are too limited for decisive conclusions, and must be viewed as merely suggestive.

The content of manganese in plants.—In Table XVIII are given the contents of manganese as Mn_3O_4 of several crops when grown on manganous phosphate. The determinations were made as follows: The powdered material was burned to an ash and then dissolved in hydrochloric acid. After adding a little ferric chloride, the iron, aluminum, and phosphorus were removed by means of the basic acetate separation. The manganese was then precipitated with bromine in a solution which was at first alkaline with ammonia and then slightly acid with acetic acid. The precipitate was ignited and weighed as Mn_3O_4.

The results show that the plants took up considerable amounts of manganese, especially the clover and serradella. It is possible that in these two cases the manganese played partially the function of calcium in precipitating oxalic acid, since manganese oxalate is quite insoluble. The writer has noticed that water extracts of acid soils often contain considerable amounts of manganese. When these soils are limed, scarcely no manganese is found in the water extract.

TABLE XVIII.—PERCENTAGES OF MANGANESE AS Mn_3O_4 IN CROPS INDICATED WHEN GROWN WITH MANGANOUS PHOSPHATE

Crops	Percentage of Mn_3O_4		
	A	B	Av.
Corn	0.324	0.324	0.324
Clover	0.832	0.800	0.816
Barley	0.225	0.227	0.226
Serradella	0.700	0.750	0.725

Since manganese may greatly affect the chlorophyll formation especially of clover and alfalfa, it seems possible that in some cases one of the reasons why soil acidity is injurious to clover and alfalfa is the presence of considerable man-

ganese in the soil solution and hence in a condition to enter the plant in considerable amounts. The variable deportment of manganese in its chemistry makes it seem all the more probable that in certain cases the effects of soil acidity may be partly due to the manganese in solution.

APPLICATIONS TO PRACTICE AND THE NEED OF FURTHER INVESTIGATIONS

In the present report no attempt is made to discuss the advisability of using one form of phosphate in preference to other forms of phosphate fertilizers. Undoubtedly many factors need to be considered in selecting the form of phosphate fertilizer that will prove the most profitable for any certain condition. Under certain soil conditions and for certain crops, where the question of immediate returns is paramount, the use of the more soluble forms of phosphate fertilizers is usually desirable. Under other soil conditions and where the farmer is in a position to build up gradually the phosphorus content and crop producing power of his soil, the use of rock phosphate in liberal amounts may be a desirable practice.

The results which have been reported emphasize especially the great differences that exist among the common agricultural crops in their power to feed on raw rock phosphate. Reasons for these differences have been pointed out, thus furnishing a firm foundation on which to base practical applications. Since the ability of a crop to utilize the phosphorus of rock phosphate depends largely on whether or not the calcium is used or removed at the same time, several desirable practices present themselves as follows:

Rock phosphate may be used to greater advantage on acid soils than on the non-acid ones, especially with crops that use small amounts of calcium. An acid soil tends to make rock phosphate available even to crops with a low calcium content, since in this case the calcium will be taken up by the soil acids. Where liming and phosphating are both practiced, it is undoubtedly better to apply the rock phosphate several months or a year in advance of the lime. This will allow a greater action of the soil acids on the rock phosphate and hence a better distribution than would otherwise be obtained. In the use of rock phosphate

provision should be made for as thorough physical and chemical distribution of the material as possible.

The great feeding power of certain plants for rock phosphate as has been pointed out, suggests the possibility of utilizing these plants for making rock phosphate more available to plants that are weak feeders on this material. Rape, white mustard, and buckwheat all have very strong feeding powers and could probably be used as cover and green manuring crops in working out rotations of this kind. The following is a suggested rotation for Wisconsin conditions:

Clover,
Wheat—seeded to white mustard after wheat harvest,
Corn—seeded to rape in last cultivation,
Oats—seeded to clover.

In this system of rotation there are three crops—clover, white mustard and rape which have strong feeding powers for rock phosphate. The white mustard and rape would be plowed under as green manures and thus not only the phosphorus that they had taken up would become available for succeeding crops, but the added organic matter in decaying would form acids which would make still more phosphate available. In this rotation, lime when used would best be applied when seeding to oats and clover. The rock phosphate could be advantageously applied to the wheat or corn crop.

Many other systems of rotation can be worked out in making use of plants with strong feeding powers. It might be of advantage, especially in short rotations, to apply the lime and rock phosphate at alternate rotations. Thus in a three-year rotation, lime would be applied every six years and rock phosphate also every six years.

Where phosphorus is needed in the growing of alfalfa, it seems that the application and thorough mixing with the soil of a liberal amount of rock phosphate should prove especially desirable and profitable.

Before advocating systems of cropping and fertilization of the kind mentioned, further careful field investigation is necessary. The condition of the phosphorus in soils, especially in regard to availability, as effected by soil acidity and liming, and the methods which may be used in attacking these problems, are all subjects needing further investigation.

SUMMARY

In this bulletin the data of many investigators are reviewed and there are reported the results of investigations extending over a period of about five years, on the utilization of phosphates by agricultural crops and the feeding power of plants.

Quartz cultures involving twelve species of plants and eight different kinds of phosphates were used in these investigations. The different species of plants showed some marked individual preferences for the different phosphates. *Solubility of the phosphates was not the only factor that determined the growth of a plant on these phosphates.*

Precipitated ferric and aluminum phosphates produced with a few exceptions good growths and in a few cases even better growths than the acid phosphate. The availability of these phosphates is undoubtedly due to ease of hydrolysis of the neutral or nearly neutral material, in which case the phosphoric acid goes into solution and there is left a basic phosphate. On continued hydrolysis these phosphates, as indicated by several investigators, undoubtedly become more and more basic and the phosphoric acid therein less and less soluble or available. It seems that these basic phosphates probably form complexes with acidic organic substances, and possibly even with acid silicates. In these combinations the phosphoric acid is probably of low availability. The advisability of using lime to aid in breaking up complexes of iron and aluminum phosphate with organic matter or acidic substances, and in helping to keep the phosphates largely in the form of calcium phosphate which has a more uniform continued availability is thus still substantiated.

The phosphorus of precipitated tricalcium phosphate was much more available than that of rock phosphate, although the form of phosphate is perhaps nearly the same in the two. Greater ease of hydrolysis of the freshly precipitated form, due partly to the physical condition, undoubtedly accounts for this.

The feeding powers of twelve common agricultural plants for raw rock phosphate has been determined under carefully controlled conditions. Great differences in the feeding powers were observed. By means of a further application

of the laws of chemical equilibrium in their relation to the solution of plant food material and feeding of plants as briefly indicated by the writer in Wisconsin Research Bulletin 20, 1912, a theory why plants vary greatly in their feeding power for rock phosphate, has been worked out as follows: *Plants containing a relatively high calcium oxide content have a relatively high feeding power for the phosphorus in raw rock phosphate. For plants containing a relatively low calcium oxide content the converse of the above is true. The explanation of this relation is made possible by means of the laws of mass action and chemical equilibrium.*

This explanation substantiates the results of other investigators, which indicate that carbonic acid is the only free acid given off in appreciable amounts by plant roots. The failure of investigators to show that there is a direct relation between the relative feeding powers of plants and the amounts of carbonic acid given off by the respective plant roots is thus also explained, since it is more largely the efficiency with which the carbonic acid acts as determined by the equilibrium conditions of the soil solution in contact with the roots, than the total amount of carbonic acid given off, that determines the feeding power.

Since the roots of plants at any one time come in contact with only a small portion of the total internal surface of the soil, and the feeding of the plant roots especially for phosphorus and potassium probably takes place largely in local soil areas, the *rate at which these elements go into solution in the local areas in contact with the roots is a more important consideration than the amount of these elements that may be drawn off from the whole soil mass in one extraction.*

The increased availability of rock phosphate when used in connection with ammonium salts is also explained by this theory as due at least partly to the increased solubility of the calcium carbonate and bicarbonate in solutions of ammonium salts. The greater availability of rock phosphate in acid soils than in non-acid soils especially to plants with weak feeding powers is also explained, since acid soils will remove the calcium carbonate and bicarbonate from solution and thus make it possible for the solubility reaction to continue.

The great feeding power of some plants, which are weak feeders on rock phosphate in quartz cultures, for the phos-

phates naturally present in the soil is explained as due to their extensive root systems which make possible a sufficiently rapid absorption of the phosphates that go into solution largely by hydrolysis. The greater apparent availability of rock phosphate to some plants in quartz cultures than under field conditions is also explained in the discussion.

In a general way the theory advanced regarding the feeding power of plants for difficultly soluble substances may be summarized as follows: Each point of contact or near contact between absorbing surface of root hairs and difficultly soluble substances may be regarded as a chemical system which strives to attain a point of equilibrium between liquid and solid phases. In this system carbonic acid and water are the main agents causing solution. In some cases the action is largely one of hydrolysis and there is formed a soluble product and an insoluble product; e. g., action of water on ferric phosphate; in other cases the action may be both by hydrolysis and carbonation and the products formed are both soluble; e. g., action of carbonated water on calcium phosphate; or only one of the products may again be soluble; e. g., action of carbonated water on feldspar. In order that the solubility reaction may continue in any of the cases, it is necessary that proportionate amounts of all the soluble products be continually removed. Thus, if a plant is to feed strongly on rock phosphate, both the calcium acid phosphate and calcium bicarbonate must be used by the plant in somewhat proportionate amounts. In this case the calcium oxide content of the plant becomes the determining factor in the feeding power. Also, if a plant is to feed strongly on ferric phosphate or orthoclase feldspar, then since in these cases only one product is soluble, extent of root absorbing surface becomes the determining factor in the feeding power of the plant. The timothy plant is a splendid example of this type. It must not be forgotten that other subordinate factors also enter, especially under field conditions where the drainage water, and under acid conditions, where the soil acids, may remove one or more of the soluble products. The movements of the soil water and the action of soil bacteria and other soil life are all factors which may disturb conditions of equilibrium at the local feeding areas and hence influence the power of a plant to feed on difficultly soluble substances.

The exceptionally high phosphorus content of the plants grown on magnesium phosphate supports Loew's hypothesis that magnesium functions as a conveyor of the phosphorus in the plant.

The high calcium oxide content found in certain plants seems to be connected with a high protein content. In protein synthesis calcium is probably used for at least two purposes: viz., In one case it enters into the protein molecule, and in the other as calcium carbonate or bicarbonate it neutralizes the poisonous oxalic acid or other acids which are probably by-products of protein synthesis. This seems to be at least a partial explanation why legumes which are high in protein grow best on a soil well supplied with calcium carbonate.

Plants grown on manganous phosphate contain considerable amounts of manganese. Manganese affects the chlorophyll formation of certain plants and especially of clover and alfalfa. Since the soil solution of acid soils often contains considerable amounts of manganese, this may explain one way in which soil acidity acts injuriously on these plants.

In the light of the present report, the application of rock phosphate to acid soils, especially several months or a year in advance of the application of lime, seems to be a desirable practice. It seems that rock phosphate may possibly be used very advantageously in the growing of alfalfa. It also seems possible that some of the plants with strong feeding powers for rock phosphate may be used advantageously as cover crops and green manuring crops and thus provide for a better utilization of the rock phosphate than is otherwise possible. This as well as the availability of the soil phosphorus as affected by different soil conditions are matters needing further investigation.

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Early Blight of Potato and Related Plants

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AGRICULTURAL EXPERIMENT STATION
OF THE UNIVERSITY OF WISCONSIN

MADISON

CONTENTS

Early Blight of Potato and Related Plants*

R. D. Rands

The potato is commonly subject to two blights, late and early. In Europe the former is the better known of the two; while throughout the rest of the world, the latter is more generally distributed. It was shown many years ago that early blight is caused by a fungus now known as *Alternaria solani* (E. & M.) J. & G.; but many points in connection with the life history of this organism, its host range, climatic relations, means of overwintering, and control measures required investigation. In this bulletin are presented the more important results of an intensive study of the disease as it has occurred in central Wisconsin during the past three years.

History and Occurrence of the Disease

The early blight of potato was not early recognized as a distinct disease, due perhaps to the general confusion of all the leaf troubles under the term "blight (*Phytophthora infestans*). As soon as attention was concentrated upon these in America, blighting of the foliage not accompanied by tuber rot was noted. Subsequent study led to the differentiation of tip-burn, arsenical poisoning, and early blight.

The causal organism of the latter was first described as a Macrosporium by Ellis and Martin (1882) from the dying leaves of potato near Newfield, New Jersey. The first reference to the fungus as a parasite and its association with potato leaf blight is that by Galloway (1891). He later (1893) states that it was first collected in Missouri in 1885 and in 1890 "complaints of its ravages" came to the United States Department of Agri-

*The writer is indebted to Prof. L. R. Jones for many helpful suggestions during the progress of the study, and the preparation of the manuscript.

culture from widely separated regions in the United States. In this paper he gives an accurate and detailed description of the disease. The fungus was grown in culture, but from the brief description it is uncertain whether these were pure. However, inoculations produced the characteristic spots in from 8 to 10 days. Following this the trouble was reported by workers in most of the middle west and eastern states. For some time there was much disagreement concerning the true cause of the disease. Some believed the Macrosporium only a secondary invader and the disease primarily of nonparasitic origin, while others considered the fungus a parasite but not the cause of all the trouble.

Jones (1893) writing of the disease reports injuries quite similar produced by paris green. Here for the first time, appears a drawing of a diseased leaf, affected unquestionably with the disease as we know it to-day. At this time he suggested the names early blight and late blight to separate the two diseases. It was not until some time later when Jones (1895, 1896) published the results of further studies that the relation of the Macrosporium to the various troubles entirely cleared up. His field and laboratory studies led him to the conclusion that the fungus was a true parasite and the primary cause of early blight. Here also he clearly differentiates the three other forms of disorder which had been confused up to that time under the name "blight," namely, late blight, arsenical poisoning, and tip-burn. Even after this the troubles were not always separated.* Since the work of Jones, very little has been added to our knowledge of the early blight disease. However, during the past two decades much valuable data have accumulated bearing upon the control of the trouble by spraying. During these twenty years, early blight has been reported from practically every state in the union. Outside the United States it has been recorded from Canada, Mexico, South America, Europe, Africa, Australia, India, New Zealand, New South Wales, and Java. Thus it probably occurs wherever the potato is an important crop. As

*As illustrating the confusion at this time, reference may be made to the Cornell Agricultural Experiment Station Bulletin 113, 1896, by E. G. Lodeman. Accompanying a description (p. 254–261) of what is called "early blight" is a colored plate of a potato leaf affected, not with early blight, but with a clear case of tip burn. In the text book, "The Spraying of Plants," by the same author, the illustration on page 346, labeled "early blight" represents a typical form of arsenical poisoning.

to whether the parasite is native to the potato and has spread with it from its original home in South America to the various countries into which the potato has been introduced is largely a matter of speculation. However, Jones (1903) reports finding it on specimens of wild potato from Mexico.

ECONOMIC IMPORTANCE

It is practically impossible to determine the actual loss caused by early blight, owing to the fact that the situation is usually complicated by the presence of tip-burn, arsenical poisoning, flea bettle injury, or late blight. Results from spraying experiments furnish no accurate basis for estimating the loss since bordeaux mixture reduces at the same time the influence of all the other troubles on the vines, and may in itself furnish a stimulus to greater vigor. All reports show that the disease is of greater consequence in the United States than elsewhere, with the possible exceptions of Australia, Rhodesia and New Zealand. Jones (1903) states that in certain seasons *Alternaria solani* causes more loss in many parts of New England than does the mildew. Several cases are on record of unusual attacks, but more important, however, is the smaller but yearly toll of the disease. Coons (1914) averages the annual loss in Michigan as about 25 per cent. In Wisconsin Jones (1912) states that it may reduce the yield 10 to 25 per cent. The writer considers these figures a conservative estimate.

In the southern states, early blight has been reported to attack seriously leaves, stems, and fruit of the tomato. Edgerton and Moreland (1913), in Louisiania, state that it is a close second to "wilt" in destructiveness and in many regions the "all important disease." In one tomato district they estimated a loss of 50 per cent.* Though the disease transfers readily to the tomato and may be found almost every year in the northern states, yet it appears to do little damage. The writer has, however, found it in both the Chicago and Madison local markets as the cause of a severe rotting of tomato fruits from the south. The evidence here indicated that the disease had developed during transit. In the summer of 1916 it was isolated along with *Gleosporium phomoides* Sacc. from decaying tomato fruits at

*Isolations of the fungus from fresh material received from Dr. Edgerton in July 1916 confirmed his diagnosis of the trouble.

Waupaca, Wis., but which fungus was primarily responsible for the trouble was not determined. Inoculation studies reported later in this bulletin show that *A. solani* is capable of producing a spotting no wise different in appearance from that on naturally infected fruit.

The disease has been found the past two seasons on eggplants in Wisconsin; it seems, however, to be of little consequence especially as compared with the leaf spot caused by *Phomopsis vexans* (Sacc. & Syd.) Harter.* In June, 1916, it was found to be causing a serious blight in seed beds of this host at Eau Claire, Wisconsin. It was learned that the hot beds had remained for a number of years in the same place and that it was the practice to sprinkle them frequently with a hose. These factors operating on the crowded, more or less etiolated seedlings may account for the rapid spread and severity of the trouble.

SYMPTOMS

The appearance of the spots on the leaves of each of the three common hosts is very similar. They are dark brown or black and show usually a series of concentric ridges which produce a "target board" effect. (Fig. 3) There is often a narrow marginal faded zone which spreads outward as the spot enlarges. The spots are usually oval in shape but under unfavorable conditions, especially on a vigorous leaf, may remain small and angular conforming to the spaces between several small veins. (Fig. 1.) The spots usually enlarge after the death of the leaf. On the tomato the disease may be

FIG. 1. EARLY BLIGHT OF POTATO

The leaf is soon weakened from the enlargement of the spots. (Photograph by L. R. Jones.)

* *Alternaria solani* was first recorded on egg-plant by Chester (1893) in Delaware. Later it was listed by Clinton (1904) in Connecticut.

easily mistaken for the leaf spot (*Septoria lycopersici*) which has been much more common on Wisconsin tomatoes during the past two seasons. Without the aid of a hand lens the spots on the egg-plant are almost indistinguishable from those caused by *Phomopsis vexans*. Early blight on the potato is readily distinguished from arsenical poisoning by the darker color of its spots. With tip-burn the leaflet usually shows apical or marginal burning and the concentric rings are absent. There is still less resemblance to the late blight because of the whitish fructification of the ventral surface of leaves affected with the latter trouble.

FIG. 2.—A SINGLE HILL OF POTATO DYING FROM EARLY BLIGHT

Early Ohio planted April 28, photographed August 12, 1915. Note the progressive curling and drying of the leaves from the ground upward.

Potato plants may be attacked by early blight at almost any stage of their existence, but, under ordinary conditions, the disease is not able to gain a foothold until the vines have passed their period of greatest vigor and are directing their energy to tuber formation.

Before this time, close scrutiny will generally reveal an occasional spot on the lower, older, and more shaded leaves of the plant. Such leaves have frequently been covered and uncovered (with soil) a time or two during the process of cultivation and are consequently yellowed and weakened. Under favorable conditions the spots increase rapidly in number, and the leaves beginning with the lower ones gradually die until only a few green, spotted leaves remain at the top of the plant. (Fig. 2.) In severe cases spots develop on the petioles and upper stems of the plant.

Studies on the Host Range of Alternaria Solani

The primary object of these studies was to determine whether the leaf spots of potato, tomato, egg-plant, and Jimson weed (*Datura stramonium*), which have been ascribed to this fungus, were produced by one and the same species of Alternaria. Jones (1896) proved beyond doubt the parasitic relationship of *Alternaria solani* to the early blight of potato, but its connection with the other plants has never been conclusively shown by inoculation tests. The failure of inoculations on Datura and the comparative studies of *Alternaria solani* and the Datura fungus show that the latter is a distinct species, bearing no similarity to *A. solani* in its host relationship. The results are published elsewhere (Phytopathology 7: 327–337, 1917)* The secondary object was to determine within what limits the parasitism of *Alternaria solani* is confined.

During the summer of 1915, pure cultures from single spores were obtained for inoculation purposes from potato, tomato, and egg-plant growing at Waupaca, Wis. They were later grown comparatively on fifteen kinds of agar media and in appearance were practically identical. Abundant spores for inoculations were obtained from each by a method later referred to.

Greenhouse Inoculations

The following inoculation methods were used with more or less success in greenhouse experiments made from February to May, 1916; temperature 19 to 23° C.

(1) Drop of heavy spore suspension placed on flat portion of leaf inclosed by round cover slip. Plant placed in glass moist chamber for 48 to 72 hours.

(2) Spores or mycelium introduced into needle punctures. Plant placed under bell jar and atomized frequently with water for 48 hours.

(3) Leaves atomized with spore suspension and for 48 hours kept moist by fine spray from nozzle.

* This Datura leaf spot which has been widely attributed to *Alternaria solani* is shown to be due to the fungus named *Cercospora crassa* by Saccardo in 1877. Examination of type specimens collected by Saccardo and of exsiccati from various parts of the United States show that the fungus was named from immature material and is really an Alternaria. The new combination, *Alternaria crassa*, with technical discription is given in the article in Pytopathology referred to above.

TABLE 1.—GREENHOUSE INOCULATIONS, MADISON. 1916

Date	Source of inoculum	Plant inoculated: condition, etc.	Method of inoculation	Results
b. 25	Potato strain. *A. solani*; mycel on bits of agar	Potato-2 plants 8-10 in. high: vig. 10 leaflets inoc..	No. 2	March 3, 80% infection; spots 8-20 mm. diam on both plants
		Tomato-1 plant vig. 10 leaflets inoc.	No. 2	March 3, 75% infection; spots 4-6 mm. diam.
r. 13	Potato strain. *A. solani*; spores from culture	*Solanum nigrum*-1 plant 4 in. high; vig.	No. 1	April 20, 90% with spots 1-4 mm. diam.
		Eggplant-1 plant 3 in. high; vig.	No 1	April 20, 100% infection; spots 1-2 cm. diam.
		White Burley tobacco-2 plants 6 in. high; vig.	No. 1	April 20, few spots 1 mm. diam. no further enlargement
pr. 13	Potato strain, *A. solani*; spores from culture	Potato-1 plant 10 in. high; vig.	No. 3	April 20, minute spots on every leaf; wet continuously
		Tomato-1 plant 8 in. high; vig.	No. 3	April 20, few spots; not wet continuously
		Eggplant-1 plant 4 in. high; vig.	No. 3	April 20, many spots on every leaf; wet continuously
ay 7	Potato strain, *A. solani*; spores from culture	Potato-1 plant 14 in. high; vig.	No. 3	May 14, many spots 1-3 mm. diam.
		Tomato-2 plants 16 in. high; vig.	No. 3	May 14, few spots on lower leaves, 2-3 mm. diam.
		Solanum nigrum -2 large plants; fairly vig.	No. 3	May 14, few spots on lower leaves, 1-5 mm. diam.
pr. 14	Eggplant strain: spores from culture	Eggplant-1 plant 5 in. high; very vig.	No. 1	April 20, 100% with spots 3-4 mm. diam.
		Potato-1 plant 12 in. high; vig.	No. 1	April 20, 90% with spots 1-3 mm. diam.
		Tomato-1 plant 12 in. high; very vig.	No. 1	April 20, 80% with spots 2-3 mm. diam: enlarge very slowly
pr. 14	Tomato strain; spores from culture	Tomato-1 plant 12 in. high; very vig.	No. 1	April 20, 100% with spots 2-3 mm. diam.
		Potato-1 plant 15 in. high; vig.	No. 1	April 20. 100% with spots 3-4 mm. diam.
		Eggplant-1 plant 8 in. high: vig.	No. 1	April 20. 100% with spots 6-8 mm. diam.

These experiments are briefly summarized in Table I. In most cases reisolations from the infected plants were successful. The results show that in the majority of cases *Alternaria solani* from potato crossed readily to tomato and egg-plant, to some extent to nightshade (*Solanum nigrum*), and to cultivated tobacco. In the latter case, penetration occurred, but the mycelium seemed to be unable to spread in the tissues of these vigorous seedlings.

The strains isolated from tomato and egg-plant reciprocally crossed quite readily and both in turn produced a spotting of potato in no wise different from that of ordinary early blight on potato. Aside from a few explainable exceptions the uninoculated needle punctures healed, and in method 3, the plants exposed beside the inoculated plants never developed spots. Therefore it seems justifiable to conclude that the early blight of potato, tomato, and egg-plant are caused by one and the same organism, viz., *Alternaria solani.*

Owing to the difficulty of working with mature plants in the greenhouse it was decided to continue the tests under field conditions.

FIELD INOCULATIONS

Field tests were carried out at Waupaca in central Wisconsin during the summer of 1916. In order to determine within what limits the parasitism of this fungus is confined, it seemed desirable to obtain a wide range of plants, especially as to genera, of the potato family. The effort was successful only to a limited extent because it was impossible, on a few months notice to get seed, particularly of the wild members of the family.*

Eight to ten plants of each species and variety were properly spaced in rows three feet apart, with every third row in potatoes to furnish a basis for comparison. The potatoes were planted May 11 and the other plants were transferred from the greenhouse in early June. The severe and prolonged drought during July and August proved a serious setback, but by artificial watering most of the plants made normal growth. Prior to Sep-

*The writer is indebted to Messrs. Peter Bisset, Plant Introducer U. S. Dept. of Agriculture, Geo. T. Moore, Missouri Botanical Garden, St. Louis, and W. S. Oswald, Minnesota Seed Labratory for seeds or plants furnished for this work.

tember 4 conditions for natural infection were very unfavorable and spots which appeared earlier on the potato did not spread. On account of the extreme heat, artificial conditions for infection could not be maintained with the means at hand. After August 15, several plants of each species were atomized occasionally with spores in order to have the plants ready for rainy weather when such a favorable condition for infection should arrive. Spores from pure culture of the potato strain were used. September 8, several leaves on selected plants of each species were inoculated by the needle prick method. i. e. by placing a drop of heavy spore suspension on each puncture but always leaving an equal number uninoculated for control. The drought was broken on September 4 when a period of moist weather with heavy dews and rains set in, furnishing ideal conditions for infection by *Alternaria solani.*

The main results from these field inoculations are presented in Table II which shows: (1) size and condition of the plants on September 19 and (2) the progress of the disease two weeks after and one month after the beginning of the rainy period.

In most cases an attempt was made to reisolate the fungus from the smaller spots even where sporulation occurred on large spots of the same plant. In several instances, it will be seen that the fungus was not reisolated though spores are recorded for the larger spots. This was probably due to the presence in the plates of the saprophytic fungus, *Alternaria fasciculata*, which is the more rapid grower and is difficult to eliminate. Inoculations on Nos. 3, 4, 5, 9, 13, 14, 24, and 26 were repeated in the pathological garden at Madison, Wis., in September and October, 1916. As the results agree in all essentials with those tabulated, for the sake of brevity they are not listed here.

The table shows that the fungus was able to penetrate almost every plant inoculated. Even the leathery, succulent leaves of *S. grandiflorum* and *S. guttata* were infected as was the potato. Leaves of the former inoculated September 2 were found to be thickly peppered with tiny infection spots September 9. These spots, which measured less than two millimeters in diameter, had made no enlargement when the leaves were again examined a month later. Yet when cultures were made from such spots, October 14, almost every one developed the fungus. What checks the advance of the fungus in the tissues of these plants is not

TABLE II—RESULTS OF FIELD INOCULATIONS WITH ALTERNARIA SOLANI ON VARIOUS GOLANACEOUS PLANTS

Plants tested	Size and condition of plants September 19	Results on September 19		Results on October 9			Reisolation of the fungus
		Atomized leaves	Needle punctured leaves	Atomized leaves	Needle punctured leaves	Spore production	
1. *Solanum aviculare* Forst.	12-14 in. high: mature, healthy	Spots 3-12 mm. diam.	90% infection: spots 3-4 mm. diam.	Lower leaves dying from the disease	100% infection; spots 4-6 mm. diam.	Abundant	Yes
2. *S. burbankii* Bittel. small wonderberry	8 in. high 24 in. wide; much weakened by flea beetle	Many specks .5-1 mm. diam.	Leaves dropped off	No enlargement		0	Yes
3. *S. pseudocapsicum* Linn. Jerusalem cherry	6-8 in. high; fairly vigorous	Peppered as above	No evidence of infection	No enlargement	No infection	0	Yes
4. *S. carolinense* Linn. horse nettle	18-24 in. wide; in fruit, vigorous	Spots 1-2 mm. diam.	80% infection; spots 2-3 mm. diam.	Spots on green leaves. 3-4 mm., on yellow leaves 6-8 mm. diam.	Leaves dying from the disease	Abundant	Yes
5. *S. giganteum* Jacq.	2-3 ft. high; very vigorous	Thickly spotted 1-3 mm. diam.	100% infection: spots 5-8 mm. diam.	Spots on old leaves 8-15 mm. in diam., on young leaves 1-4 mm. diam.	Spots 8-10 mm. diam.	Abundant	Yes
6. *S. grandiflorum* Ruiz. and Pav.	6-8 in. high; small, succulent, vigorous, leathery leaved shrub	Spots .5-2 mm. diam.	No evidence of infection	No enlargement	No evidence of infection	0	Yes
7. *S. guttata*	as above	Spots, including yellowish zone, 1-3 mm. diam.	No inoculation	No enlargement even on yellowing leaves		0	Yes
8. *S. jasminoides* Paxt. potato vine	2 ft. high; vigorous woody vine	Spots 1-1.5 mm. diam.	Margins of punctures brownish	Slight increase in size	20% infection: spots 1-2 mm. diam.	0	Yes

9. *S. melongena* Linn. egg plant	1-2 ft. high; weakened by drought	Spots .5-10 mm. diam.	100% infection; spots 8-10 mm diam.	Most of the lower leaves dead from the disease		Abundant	Yes
10. *S. nigrum* Linn. black nightshade	6-10 in. high; upper leaves fairly vigorous	Leaves atomized at Madison Oct. 21; Oct. 30, numerous spots 1 mm. diam.		Nov. 4, many spots 3-5 mm. diam.		0	Yes
11. *S. nigrum var. guinennse* Linn. garden wonderberry	3-4 ft. high; weakened by drought and red spider	Thickly peppered .5-1 mm. diam.	Leaves dropped	Yellowed leaves, spots 3-15 mm. diam.		Few	No
12. *S. rostratum* Dunal. buffalo burr	18-24 in. high; fairly vigorous	10-15 spots per leaf 3-5 mm. diam.	100% infection; spots 8-10 mm. diam.	Lower leaves yellowing and dying from abundance of spots		Abundant	Yes
13. *S. tuberosum* Linn. early Ohio	12 in. high; young upper leaves vigorous	Many spots, 3-5 mm. diam., coalescing	100% infection: spots 3-6 mm. diam.	Leaves dying from disease		Few	Yes
14. *S. warszewiczii* Hort.	1-3 ft. high; very vigorous	Peppered with spots 1-4 mm. diam.	100% infection; spots 3-4 mm. diam	Leaf yellowing; spots 3-8 mm. diam.	Lower, older leaves; spots 10-15 mm. diam.	Abundant	Yes
15. *S. wendlandii* Hook.	2 ft. vigorous leathery leaved woody vine	Thickly spotted 1-4 mm. diam.	100% infection; spots 1-4 mm. diam.	Leaves on the ground; no increase in size of spots		0	Yes
16. *Physalis francheti* Mast. Chinese lantern plant	8-10 in. high; very vigorous	Few specks, .5-1 mm. diam.	Faint browning about punctures	Few minute elevated dots	No further development	0	No
17. *P. pubescens* Linn. husk tomato	12-16 in. high; much weakened by drought and red spider	Few spots on yellowed leaves 2-3 mm. diam.	Leaf dropped	No enlargement; leaves on ground		0	Yes
18. *P. virginiana* Mill. wild ground cherry	12-16 in. high; weakened by drought	Few small spots	No inoculation	No further development		0	
19. *Nicandra physalodes* (L.) Pers. apple of Peru	2-3 ft. high; fairly vigorous	Many spots 1-10 mm. diam.	90% infection; spots 5-12 mm. diam.	Leaves yellowing and dying; spots 3-10 mm. diam.	Leaves dying from the disease	Abundant	Yes

TABLE II—RESULTS OF FIELD INOCULATIONS WITH ALTERNARIA SOLANI ON VARIOUS SOLANACEOUS PLANTS—Continued

Plants tested	Size and condition of plants September 19	Results on September 19		Results on October 9			Reisolation of the fungus
		Atomized leaves	Needle punctured leaves	Atomized leaves	Needle punctured leaves	Spore production	
20. *Lycopersicon esculentum* Mill. Yellow peach	18-24 in. high; fairly vigorous	Spots abundant 1-5 mm. diam.	No inoculation	Lower leaves dying from abundant spots		Few	Yes
Red currant	16-18 in. high: weakened by drought	Spots abundant 1-5 mm. diam.	No inoculation	Most of leaves dead due to the disease			
Dwarf stone	10-20 in. high: very vigorous	Abundant spots on lower, faded leaves, 1-4 mm. diam.	No inoculation	Some enlargement		Few	
Stone	18-24 in. high; fairly vigorous	Spots on all mature leaves 2-6 mm. diam.	40% of punctures with browned margins, leaf young	Some enlargement	Spots 1-3 mm. diam.	Few	Yes
Earliana	As above	As above	No inoculation	Some enlargement		Few	
21. *Capsicum annuum var. grossum* Linn. green pepper	12-14 in. high; vigorous, in fruit	Peppered with spots, .5-1 mm. diam.	Margins of punctures brownish	No increase; raised margins of spots indicate healing	No change	0	Yes
22. *Nicotiana alata var. grandiflora* Comes. ornamental tobacco.	18-24 in. high; fairly vigorous	Peppered as above; spots on old leaves, 2-4 mm. diam.	As above	No enlargement; dying leaf at base with few dead areas 8-10 mm. diam.	No change	Few	No
23. *N. tobacum* Linn. White Burley	4-5 ft. high; lower mature leaves healthy	No evidence of infection	No change	No change	Margins of punctures healed	0	

24. *Hyocyamus niger* Linn. black henbane	8-12 in. high; vigorous	Numerous spots 1-5 mm. diam.	60% infection; spots 3-8 mm. diam	Spots 3-10 mm. diam.	Spots further enlarged	Abundant	Yes
25. *Petunia hybrida* Hort. white petunia	10-20 in. high; vigorous	Numerous elevated specks	40% infection; spots 1-4 mm. diam. light colored	Spots barely visible	No change; leaf yellow	0	Yes
26. *Lyceum vulgare* Dun. matrimony vine.	2-3 ft. long; leaves weakened by red spider	Many small specks, .5-1 mm. diam.	Slight browning about punctures	No change	No change	0	No

known. It is believed that such plants, i. e., those on which the spots do not enlarge, should not be considered as hosts, since on them the fungus does not produce spores and therefore can-

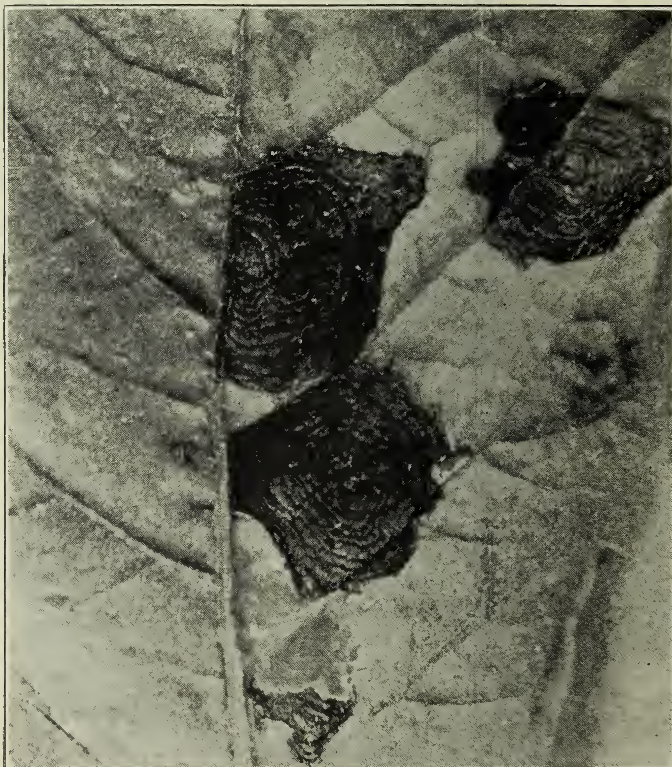

FIG. 3.—POTATO EARLY BLIGHT SPOTS ENLARGED X 3

These show the typical black target board appearance. (Photograph by H. H. Whetzel.)

not complete its life cycle. On this basis the hosts of *Alternaria solani* determined by these studies are listed below.*

1. *Solanum aviculare* Forst.
2. *Solanum carolinensis* Linn.—Horse nettle
3. *Solanum giganteum* Jacq.
4. *Solanum melongena* Linn.—Egg-plant
5. *Solanum nigrum* Linn.—Nightshade
6. *Solanum nigrum guinennse* Linn.—Garden wonderberry

*Though not included in these studies it is probable that the two following species are also hosts of *A. solani.*

Solanum commersoni Dun. listed by Nusslin (1905) and Stuart (1914).

Hyocyamus albus Linn. White Henbane, according to Ferraris (1913).

7. *Salonum rostratum* Dun.—Buffalo burr
8. *Solanum tuberosum* Linn.—Potato
9. *Solanum warscewiczii* Hort.
10. *Hyocyamus niger* Linn.—Black henbane
11. *Lycopersicon escûlentum* Mill.—Tomato
12. *Nicandra physaloides* Gaertn.—Apple of Peru

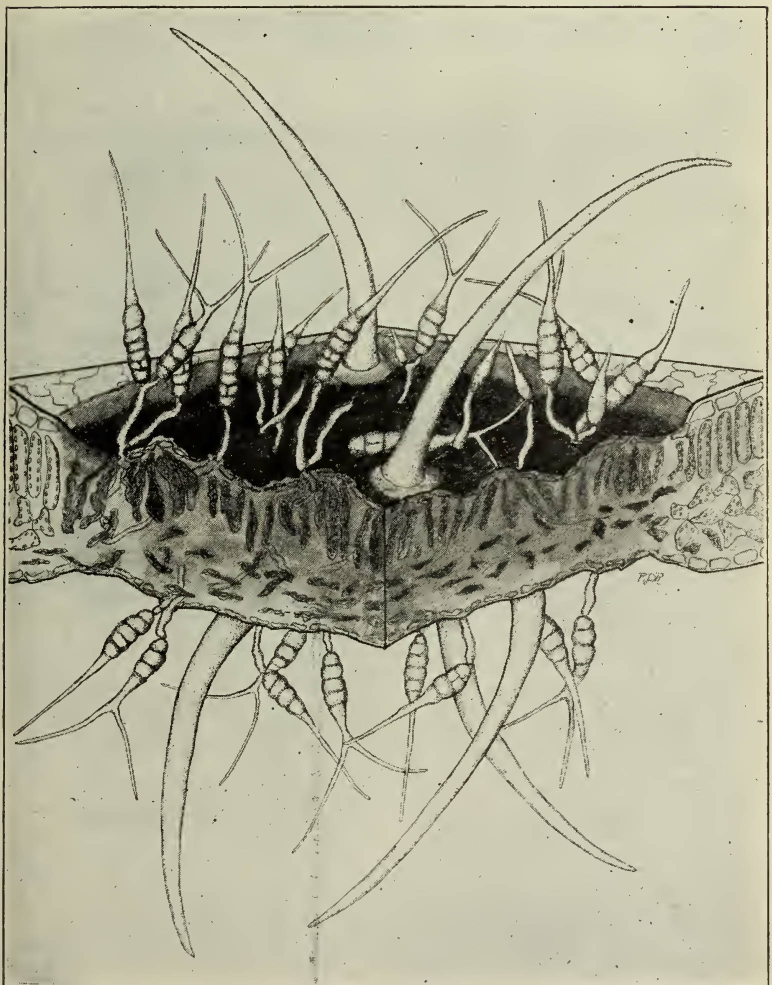

FIG. 4.—DIAGRAMMATIC REPRESENTATION OF A PORTION OF SPOT ENLARGED

The invaded tissue shrinks to about one half the original thickness of the leaf, and the surface is thrown into concentric ridges. The cells are darkened. Spores are produced on both surfaces as shown above intermingled with the hairs.

During May, 1916, inoculations were made on tomato fruits of various ages freshly picked from greenhouse plants. In two

trials spores atomized on the surface failed to give infection after 10 days even though the fruits were moistened frequently and kept in a damp chamber. Under the same conditions needle puncture inoculations invariably resulted in infection. After 15 days there was only slight invasion about the points of inoculation on the green fruits while with the ripe fruits almost complete rotting resulted. McCubbin (1916) in Ontario, reports similar results from inoculations of tomato fruits. Needle puncture inoculations were made on mature fruits of egg plant and green pepper during August, 1916. In each case slight invasion of the tissues about the punctures occurred but no enlarged spots or decay resulted.

Of the nine genera of the potato family tested, four only were found able to perpetuate the fungus, viz., Solanum, Lycopersicon, Nicandra and Hyocyamus. Of these the Solanums though showing considerable variation appear as a group to be the most susceptible. From these experiments it is evident that *A. solani* is not restricted within very narrow limits in its host relationship.

PATHOLOGICAL ANATOMY

An explanation of the "target board effect" (Figs. 3 and 4) characteristic of this disease is suggested by Jones (1896). He believes that such a condition is produced by the more complete collapse and rapid contraction of the interior cells or mesophyll as compared with the epidermal cells. A study of microtome sections of spots in various stages of development shows that greatest contraction occurs in the spongy tissue which would tend to throw the upper part of the leaf into concentric folds.

In the spot the cells are collapsed, shrunken, and deeply stained (Fig. 5). No evidence has been obtained to show that the failure of small spots to enlarge on vigorous leaves was due to suberized layers or other mechanical hindrance to invasion. On the contrary, all evidence indicates the resistance to be directly related to the vigor of the leaf. Though the fungus has never been actually observed inside the cells of the host, there seems no reason to suppose that it cannot enter them. Penetration of the leaf usually occurs directly through the epidermis, and in pure culture the fungus can utilize cellulose when this is offered as its only source of carbon.

The Causal Organism

TAXONOMY

In the literature on early blight the fungus is commonly referred to under the following names—*Macrosporium solani* Ellis and Martin, *Alternaria solani* (E. & M.) Jones and Grout, and *Alternaria solani* Sorauer. In foreign references the latter is in more general use while the second occurs most frequently in accounts of the disease in America. Sorauer (1896) published

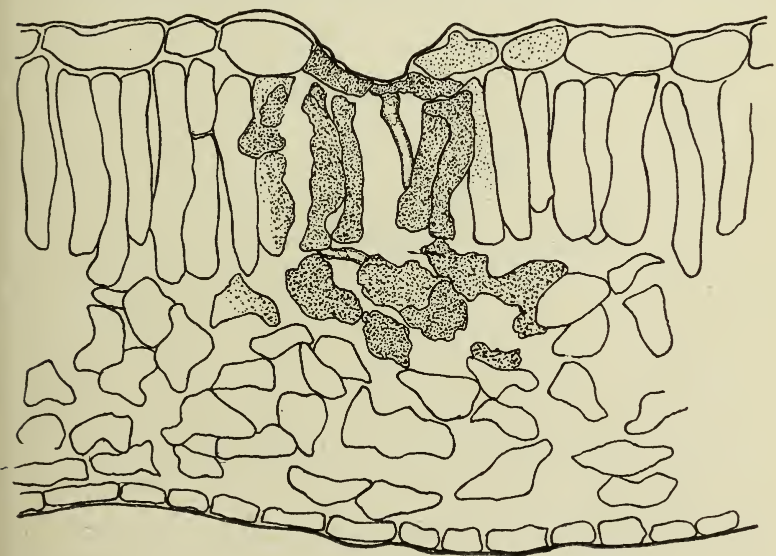

FIG. 5.—CROSS SECTION OF LEAF SHOWING INCIPIENT INFECTION OF ALTERNARIA SOLANI

Penetration usually occurs directly through the cuticle. Shrinkage follows the death of the cells. X450.

on the fungus a few months in advance of Jones (1896), but his observations and illustrations of spore chains, as he found them in crude hanging drop cultures, show plainly that his description was based on *Alternaria fasciculata.* From type material received from Sorauer, Jones separated the two fungi, the one a typical Alternaria and a saprophyte which he subsequently named *Alternaria fasciculata,* and the other the true parasite (*Macrosporium solani*). Jones reports frequent cases where spores in cultures of the Macrosporium were joined in catenulate pairs after the fashion of the Alternarias. He then writes a

technical description and gives Sorauer the credit for the new combination. Seymour (correspondence), however, later ruled that inasmuch as Sorauer had applied the binominal confusedly, authority for the new combination should rest with Jones and his assistant (Jones and Grout 1897). This is the usage of Farlow (1905) and of most recent American authors. McAlpine (1903) and Duggar (1909) have objected to calling the fungus an Alternaria on the ground that the catenulation of spores does not occur in nature. The author has examined many spots and

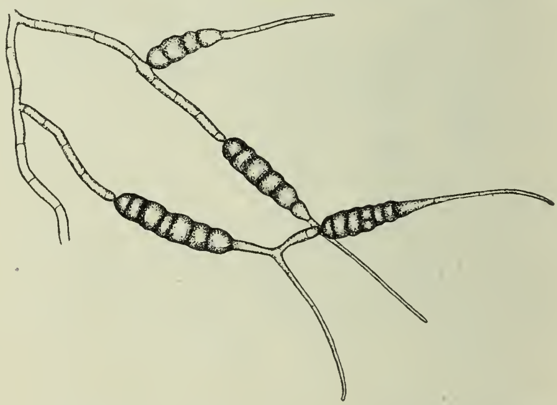

FIG. 6.—MATURE SPORES OF ALTERNARIA SOLANI

Spores drawn from pure culture where catenulation has been noted. X200.

has never seen catenulation on the leaves. It is true, however, that on oat meal agar cultures, spore pairs frequently occur (Fig. 6). In view of the chaotic condition of the literature dealing with Macrosporium and Alternaria and the slight and uncertain distinctions between the genera, the author considers it inadvisable to break away from the well established usage and go back to Mascrosporium.

The following is the probable synonomy of the fungus with citations to the literature:

Alternaria solani (E. & M.) Jones and Grout.
Bull. Torrey Bot. Club **23**:353. Sept. 1896.
Vt. Agr. Exp. Sta. Rept. **10**:45. 1896.
Macrosporium solani E. & M.
American Naturalist **16**:1003. 1882.
Macrosporium solani Cooke. (in part)
Grevillia **12**:32. 1883.
Macrosporium cookei Sacc. (in part). (following Cooke)
Sacc. Sylloge Fungorum **4**:530. 1896.

Alternaria solani Sorauer (in part).
Zeitschr. für Pflanzenkrankheiten **6**:6. 1896.
Sporidesmium solani var. *varians* Vanha.
Naturw. Ztschr. Land-u. Forstw. **2**:113–127. 1904.

MORPHOLOGY

The mycelium at the margin of the spot can be seen, using *in toto* fixations, as slender, radiating, sparsely branched filaments. Later it becomes closely branched, irregular, and deeply stained. Conidiophores have never been found arising nearer than one-

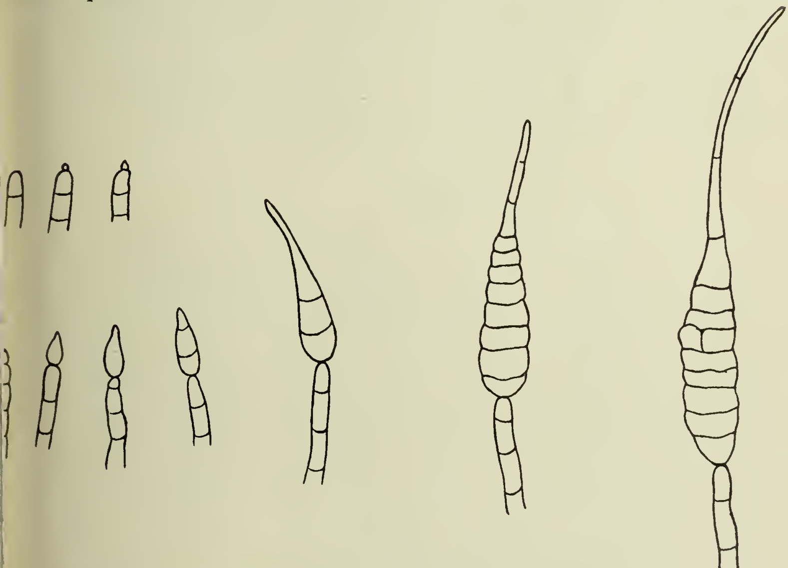

FIG. 7.—SPORE DEVELOPMENT OF ALTERNARIA SOLANI

Progressive stages commencing in the upper left hand corner. Note that the spore starts by budding from the tip of the apical cell of the conidophore as shown in the second and third stages. Drawn from culture X400.

half a millimeter from the boundary of green tissue. Usually one spore is produced on a conidiophore. The conidia arise from the conidiophore, not by the constriction and subsequent enlargement of a terminal cell, but from a bud which forms on that cell. (Fig. 7.) The first indication of the bud is a faint hyaline area on the wall. Soon (often within a few minutes), the wall at this place pushes out and forms a minute projection which has an extremely thin wall and is less than one-fifth the diameter of the conidiophore. This bud grows very rapidly at first and, on this account, the early stages are not easily followed.

A method for obtaining abundant sporulation in pure cultures of this fungus is described elsewhere.* Spores thus produced show greater uniformity in size than those from the spots. Measurements of 100 spores from large, typical early blight spots on potato leaves gave a range in size of 120–296 x 12–20 microns, an average size of 200 x 17 microns. The same number taken from several pure cultures on potato agar gave a range of 104–184 x 14–18 microns, an average of 141 x 16 microns.

Nothing to date has indicated the existence of a perfect stage of this fungus. Overwintered material has been examined and the fungus has been grown on many kinds of media of varying degrees of acidity and exposed to various temperatures but no indications of another stage have developed.

PHYSIOLOGY

Alternaria solani is easily isolated from the spots or from spores, and grows well on all the ordinary culture media. Perhaps the most striking physiological characteristic of the fungus is the intense discoloration which it produces in the medium. On potato agar, young colonies cause a clear yellow pigmentation which, as the colony enlarges, spreads in advance of the mycelium and is eventually succeeded beneath the older part by a deep wine color. In media made +20 Fuller's scale, the coloration approaches a deep brick red in some cases. On slightly acid media the yellow pigmentation predominates and it is practically absent in alkaline media, where also little growth occurs. There is likewise no discoloration when the fungus is grown on +10 to +15 casein agar, nutrient gelatin containing dextrose, starch-nitrate agar, and cellulose agar. After 7 to 10 generations in pure culture the pigmentation is much diminished and in some cases has been observed to almost disappear.

The fungus readily liquefies the above gelatin medium and shows great proteoclastic activity in the utilization of casein as indicated by the clear zone surrounding the colony when lactic acid is added to a casein agar plate. Nitrates are quickly reduced to nitrites and even to ammonia when tested on starch-nitrate agar.

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*Phytopathology 7: 316–317. 1917. This method consists, first, in severely wounding the mycelium by shredding a ten day old culture of the fungus on potato agar, and second, for 24 hours, controlling the moisture relation so that the surface does not become dry.

Temperature relations.—Both spore germination and colony growth of *A. solani* are greatly influenced by temperature. At 20° C., ordinarily five to ten germ-tubes arise from the different cells of a single spore, while at 1–3° C., germination will finally occur, but with no more than 2 or 3 germ-tubes. (Fig. 8.) Spores germinated at a low temperature generally produce several

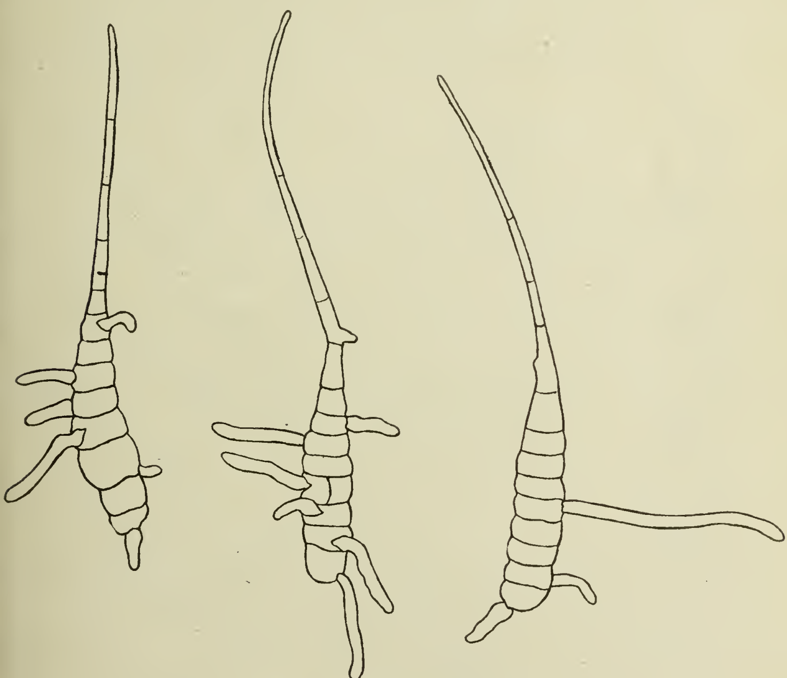


FIG. 8.—GERMINATION OF SPORES OF ALTERNARIA SOLANI

Temperature is an important factor in determining the number of germ tubes and the rate of germination; the two spores to left with the greater number of germ tubes after 1½ hours at 35° C.; the spore to the right with fewer germ tubes after 46 hours at 1-2° C.

more germ-tubes when removed to a higher temperature. Extended studies have been made of spore germination in agar under seventeen different temperatures ranging from 2 to 45° C., in which at intervals the approximate length and number of germ-tubes were determined. These results are plotted in Fig. 9. At all temperatures from 6 to 34° C., the spores germinated within one and one-half hours. Germination took place most rapidly at 28–30°, requiring at those temperatures but 35 to 45

minutes. The germ-tubes formed at 37° were irregular and knotted with bladder-like swellings at the tip. Growth entirely ceased after six hours and subsequent transference to a lower temperature showed that they were dead. At 45° the spores were killed before any indication of germination appeared.

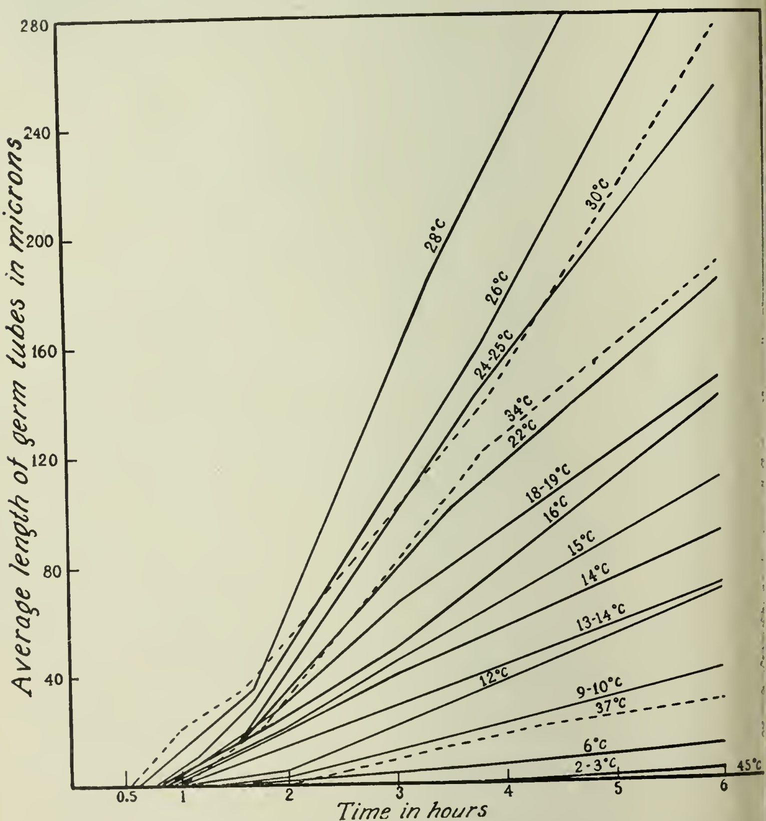


FIG. 9.—THE EFFECT OF VARIOUS TEMPERATURES ON SPORE GERMINATION AND GROWTH OF ALTERNARIA SOLANI

At most temperatures germination commenced during the first hour. The optimum is 26-28° C. At 45° C the spores were killed.

Measurements of colonies grown at these different temperatures give a graph similar to that obtained for spore germination. However, no growth visible to the naked eye took place at 3° or at 45°C., while at 37° there was a slight amount of aerial mycelium. The cardinal temperatures of the fungus are therefore approximately as follows: minimum 1°–2°C., optimum 26°–28°, and maximum 37°–45°.

LIFE HISTORY OF A. SOLANI IN RELATION TO EARLY BLIGHT

SEASONAL DEVELOPMENT OF THE DISEASE

The time at which this disease makes its appearance each year seems to depend largely upon the date at which the crop was planted and upon its subsequent development as influenced by soil and climate. It may be safely concluded that as soon as the crop has passed its stage of greatest vigor and tuber formation has begun, early blight may develop. Whether or not the attack becomes severe depends almost entirely on influencing factors later enumerated.

SPORE PRODUCTION

Spore production is usually delayed until after the death of the host tissues. Very rarely are spores found on spots less than four millimeters in diameter. Both upper and lower surfaces of a spot produce spores, the upper much more abundantly, however. They are very easily dislodged, especially by rainfall. While considerable variation has been noted in the relative abundance of spores on spots of different sizes, it was desired to get some idea of the actual numbers which may occur. For this purpose, spots developed under as favorable natural conditions for sporulation as possible were obtained and counts made. Each spot cut carefully from the leaf was rinsed in a given volume of water which, with a small amount of leached agar, was poured into a level petri dish. One-tenth areas were marked off with a bacteriological counting card. After germination had begun the spores in two such areas were counted by means of the low power of the microscope. The following results were obtained:

Diameter of spot	Distribution as noted on spot	Number of spores
10mm.	Apparently equally abund. on both surfaces	1475
7mm.	Few below, abundant above	930
10mm.	About one-half as many below as above	785
5mm.	Few below, abundant in center above	415
8mm.	Scattered on both surfaces	140
6mm.	Few on both surfaces	115

These figures may give some idea of the abundance of spores which may be produced on a badly diseased plant with, for instance, ten to fifteen spots on every leaflet. The total number

TABLE III.—DEVELOPMENT OF EARLY BLIGHT SPOTS AND SPORULATION OF ALTERNARIA SOLANI ON EARLY OHIO, WAUPACA, WIS., 1916

SPOT HISTORIES IN RELATION TO CLIMATIC CONDITIONS JULY 13-28

Leaf and Spot Nos.	13th. Light dew, clear, warm	14th. Rain .2, heavy dew, clear, warm	15th. Rain .23, lvs wet until 9 a. m., clear, warm	16th. Heavy dew, clear, warm	17th. Heavy dew, cloudy, rain .03 (Showers a. m.) p. m. clear, warm	18th. Medium heavy dew, clear, warm	19th. Light dew, clear, warm p. m. Cloudy, rain (.15). (Notes made before rain)	20th. Light dew, clear, warm	21st. Very heavy dew, clear and warm	22nd. Very light dew, clear, warm	23rd. Light dew, clear, warm	24th. Light dew, cloudy, rain (.05) 10-12 a. m.	25th. Heavy dew, cloudy, windy	26th. No dew, clear, warm; plants watered heavily with hose 5 p. m.	27th. Very light dew, clear, warm	28th. No dew, clear, warm
1a	5x8 mm. lf. vig: sp. + ab. — bl.				8x12 mm.sp. o ab; ++ bl.	8x14 mm. sp. +++ ab. bl; lf. yellowing	9x15 mm. sp. —over center ab: scattered bl. (not removed)		10x15 mm. sp. —scattered ab. bl; 1flt. dead	No change						
1b					5 mm. sp. o, lf. vig.	6 mm. sp. +++ ab. bl.	7 mm. sp. —ab; ++ bl.		7x8 mm. sp. ++ ab. bl. esp. along veins: lf. vig.	7x8 mm. sp. o		14 mm. sp. o ab: ++ bl. esp. on veins and later growth rings		14 mm. sp. +++ ab.; — bl: lf. partly dead		
2a						8x13 mm. sp. +++ both surfaces	11x19 mm. sp. — scattered ab; ++ in places bl.		12x19 mm. sp. ++ in outer rings ab. —bl; lf. dead	Unchanged, sp. o; lf. dropped						
2b							4x6 mm. sp. o		7x9 mm. sp. ++ ab. bl; more ab.	7x9 mm sp. o: lf. dying		No change; lf. dead				
3a						7x12 mm. sp. ++ both surfaces	7x15 mm. sp. o		9x15 mm. sp. +++ ab. bl.	12x18 mm. sp. o		12x18 mm. sp. o; lf. dead		No change; sp. ++ ab. bl. esp. in later growth rings		15x18 mm. sp. +++ ab. in belt 8-10 mm. from center of spot: +++ bl. upon veins

3b						3x 4 mm. Sp. o	3x5 mm. sp. — in center ab; o bl.		4x6 mm. sp. ++ in ctr. ab: — bl.	6x8 mm. sp. o		7x9 mm. sp. ++ ab. bl in center		12x13 mm. sp. ++ ab. bl. esp. on veinlets		
3c									4x5 mm. sp. +++ ab. bl.			8x9 mm. sp. ++ ab. bl. in center		14 mm. sp. +++ ab: places bl; lf. dead		
4a						4x9 mm. Sp. o	6x10 mm. sp o		8x11 mm. sp. o	8x13 mm. sp. o		10x14 mm. sp. o		No change: sp. ++ ab. near ctr; — bl: lf. dead		Sp. o.
4b						4x5 mm. —sp. ab.			5x8 mm, sp. +++ ab. bl; lf. dead			6x9 mm. sp. o but ++ A. fasciculata				
5a						8x10 mm. sp. ++ more bl. than ab.	10x12 mm. sp. — young, ab. bl.		10x12 mm. sp. o; leaf dead			No change				
6a						9x10 mm. Sp. +++ both surfaces	10x12 mm. sp. o		11x14 mm. sp. ++ entire spot ab. bl; dead			11x14 mm. sp. o				
7a						4x6 mm. sp. o ab. — bl.	5x7 mm. sp. — ab. ++ outer rings bl.		8x10 mm. sp. ++ ab. bl.			10x11 mm. sp. ++ ab. bl. esp. on veinlets		10x13 mm. sp +++ ab. less ++ bl.		Sp. o
7b						3x7 mm. Sp. o	4x7 mm. sp. o		4x7 mm. sp. ++ ab. bl; lf. dead			4x7 mm. sp. o		14 mm. sp. +++ ab. places bl. lf. dead		

Abbreviations: lf., leaf: lflt., leaflet: sp., spore, or sporulation: ab., above; bl., below; +++, very abundant; ++, abundant: +, many; —, few; o, none.

may be further increased during favorable weather by the maturity of a second or even a third crop of spores.

Effect of various factors on spore production; spot histories.—By following the history of a number of spots, a better idea was obtained of the effect of various environmental conditions on the progress of the disease. For this study, Early Ohio plants were selected showing a few scattered spots on the mature leaves. Each spot was measured with a millimeter scale and both surfaces were examined for the presence of spores with a small low power microscope. Meanwhile great care was taken not to injure the leaves in any way. If spores were present their relative abundance was noted after which they were rinsed and brushed off by use of a pipette of distilled water and a soft camel's hair brush. The spot tissue became somewhat wet but the heat of the day caused it to dry out again in a few minutes. The results of these observations are shown in Table III. The effect of light rainfalls, especially those of July 17 and 24, in removing the spores from the upper surface of the exposed spots is seen. The most important evidence obtained relates to the ability of the spot for continued spore production. It shows that the same area on some of the spots produced three and four abundant crops of spores. There is also some evidence on the relation of rain and dew to spore production. It seems quite certain that the unusually heavy sporulation noted on July 18 was largely the result of the moist period beginning with the heavy dew of the night of the 16th and continuing through the forenoon of the 17th; then a fairly heavy dew that night was sufficient to stimulate the fungus to unusual spore formation. Another instance seeming to corroborate this evidence is that of July 21 when spores were found generally abundant. Here the relatively cool weather on July 20 following the rain of the 19th and the very heavy dew that night furnished the proper conditions for spore production.

To obtain further evidence on the effect of rain and dew on spore formation, another series of spots was studied. These observations extended from August 25 to September 6, 1916. Three large plants of the Green Mountain variety, bearing many spots on most of the leaves, were selected. Plant A was protected from dew at night, and from rains, when imminent, by placing over it a dew-proof cage. Plants B and (

were not protected. The spots were examined as in the previous study, but instead of removing the spores with water and camel's hair brush, the brush alone was used. This method was equally effective while being easier of manipulation. The results from this series are shown in Table IV. Fortunately a rather dry period was selected for this study which made it possible to determine the effect of the single factor, dew, on spore formation. Prior to this experiment, the writer had believed that moderately heavy dews were sufficient to induce abundant sporulation of the fungus. The observations recorded in Table IV show that even very heavy dews each night were, with few exceptions, insufficient. The period of the experiment was marked, as a whole, by rather cool weather (see Fig. 10) and where heavy dews are recorded it is positive that the plant surface was wet from 8 p. m. until 7–8:30 a. m. Dews alone were not sufficient but they, when aided by .9 in. rainfall (Sept. 5), caused abundant sporulation on all the spots exposed. Plant A, protected, showed none or only a few spores on the spots. Therefore, concluding from both experiments, it appears that frequent rains aided by heavy dews furnish the essential moisture conditions for optimum spore production of *A. solani* in nature.

VIABILITY AND LONGEVITY OF MYCELIUM AND CONIDIA

Jones (1896) states that the mycelium in the spot retains its life for a year or more. The writer's results in the main corroborate this. Leaves dried between layers of cotton yielded the fungus from both small and large spots when isolations were made after 12 and 18 months. Material 29 months old, apparently as well preserved, gave no growth of the fungus in several attempts at isolation. There is no evidence of the existence of any differentiated or resistant form of mycelium in the spots. In pure culture, mycelium in prune agar was found viable after seven months. Potato agar plates, tested for viability after 15 and 17 months gave negative results. The recent work of Bartram (1916) shows conclusively the great resistance of the mycelium of this fungus in pure culture to very low temperatures.

The condia are also very resistant. Jones (1896) succeeded in germinating conidia one year old but obtained no growth from those two years old. In one instance the writer got 10 per cent germination after 17 months at room temperature.

TABLE IV.—SPOT HISTORIES ON GREEN MOUNTAIN VARIETY: AUG. 25–SEPT. 6, 1916

Date and Weather Conditions	Plant A. Protected from Rain and Dew							Plant B. Exposed to Rain and Dew				Plant C. Exposed to Rain and Dew		
	Leaf 1a	Leaf 2a	Leaf 3a	Leaf 4a	Leaf 5a	Leaf 6a	Leaf 7a	Leaf 1b	Leaf 2b	Leaf 3b	Leaf 4b	Leaf 1c	Leaf 2c	Leaf 3c
Aug. 25. No dew; cloudy, windy, cool	3 spots 4x5mm. no spores	2 spots 5x8mm. few spores both surfaces	4mm. few spores both surfaces	8mm. no spores	6mm. no spores	2 spots enormous sporulation	12mm. few spores center both surfaces	6mm. 2 spots none above, few below	Large marginal spot, enormous sporulation both surfaces	4mm. few spores above, none below	12x14mm. enormous sporulation both surfaces	15mm. abundant spores above, few below	8x12mm. few spores above, none below	8mm. 2 spots, no spores
Aug. 26. No dew; cloudy, windy. cool														
Aug. 27. Med. dew; partly cloudy, cool														
Aug. 28. Very heavy dew; partly cloudy, warm	No spores	No spores	No spores	No spores	No spores	No spores	No spores	No spores	No spores	No spores	No spores	No spores	No spores	No spores
Aug. 29. Heavy dew; clear, warm														
Aug. 30. Very heavy dew; clear, windy, warm	No spores	No spores	No spores	No spores	No spores	No spores	No spores	No spores	No spores	No spores	No spores	No spores	No spores	No spores

Aug. 31. No dew; clear, windy, cool														
Sept. 1. Heavy dew; cloudy, cool; mist in A. M.														
Sept. 2. Heavy dew; cloudy, cool	No spores	No spores	No spores	No spores	No spores	No spores	No spores	No spores	No spores	No spores	No spores	Spores abundant in center above, few below	No spores	Spores scattered over upper surface, none below
Sept. 3. No dew; clear, windy, warm														
Sept. 4. No dew; rain (.27) 6 A. M. vines wet until 10 A. M. cloudy, warm														
Sept. 5. Light dew; rain (.9) 8 A. M.-5 P. M.	Leaves dying from tip-burn & early blight							Leaves mostly dead at this time from tip-burn and early blight						
Sept. 6. Very heavy dew; foliage wet until 10 A. M. clear, warm P. M.	No spores	No spores	Very few spores scattered above	No spores	Few scattered spores both surfaces	Few scattered spores	No spores	Spores very abundant both surfaces	Enormous sporulation both surfaces of entire leaflet	Abundant sporulation both surfaces	Very abundant sporulation both surfaces	Leaf fallen	Very abundant sporulation both surfaces	Very abundant sporulation both surfaces

DISSEMINATION OF CONIDIA

The suddenness of appearance of a general and severe infection of early blight following a period of favorable weather has been noted by various workers. Observational data accumulated during the summers of 1915 and 1916 seem to indicate that the wind is the chief agent of dissemination in such cases. For instance, a field of early potatoes at Waupaca, Wisconsin, was noted to be suffering severely from early blight and tip-burn to the extent that on September 11, 1916, the majority of the vines were dead while an adjacent field of Rurals on the south was green and showed but relatively few spots. However, on a strip of the latter about 80 feet wide, adjacent to the early field, the disease was much more prevalent, but the number of spots was noted to decrease as one proceeded from the boundary line. To determine the relative occurrence of spots, typical leaves were picked from the first two or three rows next to the early field and an equal number 75 feet back. The spots were counted, including all the leaflets on each compound leaf. 12 leaves of lot 1 each bore 45 to 356 spots, average 175 spots per leaf; 12 leaves of lot 2 each bore 20 to 141 spots average 71 spots per leaf. Since potato beetles were practically absent from this field and strong north winds with favorable conditions for spore production and infection had occurred the preceding week, all evidence pointed to the wind as responsible for the general dissemination over this adjacent area.

There seems to be little doubt that the Colorado beetle is another agent of distribution for Alternaria spores. Twice during July, 1916, the examinations of washings from the beetles were made. Fifty adult beetles collected from diseased potato vines were dipped and shaken for a moment in ten cubic centimeters of sterile water from which microscopic examination and poured plates showed abundant spores. Numerous contaminating saprophytes prevented the actual number of spores from being determined.

METHOD OF INFECTION

According to Jones (1896) penetration may occur either through the stomates or directly through the cuticle. With proper conditions the young leaves of a plant can be infected as

readily as the older ones but the rate of enlargement of the spot is distinctly slower in the young leaves.

Though infections in nature frequently occur about flea beetle holes, the observations of several earlier investigators as well as those of the writer indicate no necessary relation between the two. It is not improbable, however, that these little beetles may carry the spores, as is shown for the Colorado beetle and as a result inoculate the wounds they make.

PERIOD OF INCUBATION

In the greenhouse where the cover slip method was used the incubation period both for potato and tomato, varied from 28 to 50 hours. Under field conditions, relying entirely upon heavy dews for the necessary moisture, incipient spots were usually noticeable within 48 to 72 hours after the spores had been atomized upon the plant. Under favorable conditions, within three or four days these spots may enlarge and produce spores which can cause secondary infection on adjacent leaves or plants.

TIME OF NATURAL INFECTION

As observed in central Wisconsin, natural infection is generally first visible from June 20 to July 10 on the crop planted April 25 to May 15. On the late crop, spots may be observed from the middle of August on, depending apparently upon three factors: age, vigor of plant, and weather conditions.

SOURCE OF NATURAL INFECTION

The source of inoculum for the early crop is probably from the overwintered spores and possibly from new conidia produced by overwintered mycelium which has been harbored in the soil in the debris of former crops. It is quite likely that an additional source of infection of the late potatoes is from nearby early fields in the form of spores carried by the wind or by potato beetles seeking the younger and more tender plants.

OVERWINTERING OF THE FUNGUS

The problem of the overwintering of *Alternaria solani* is concerned with but two possibilities, i. e., conidia and mycelium.

It has already been shown that both these structures possess remarkable resistance toward unfavorable conditions.

The writer has no evidence to substantiate, and sees no reason for accepting, the hypothesis offered by Massee (1906) and endorsed by McAlpine (1911) that the disease is transmitted from one generation to another by latent mycelium in the tubers.

To determine definitely under what conditions the fungus can overwinter in Wisconsin, the following experiment was made. On July 22, 1915, some very good material showing abundant sporulation was collected and the leaves dried quickly in the open air. In October, a 6 x 10 foot plot in the plant disease garden at Madison was marked off into four strips and used as follows:

In No. 1—Diseased leaves on the surface
In No. 2—Diseased leaves buried two inches deep
In No. 3—Diseased leaves buried four inches deep
In No. 4—Diseased leaves buried eight inches deep

The leaves were protected by being placed between one thickness of cheese cloth and this in turn was placed between two layers of galvanized iron wire netting. At intervals throughout the winter material was removed from each strip and attempts were made to isolate the fungus from it. The bulbs of soil thermographs were buried four and eight inches in the plot to furnish a continuous record of the soil temperatures, while an air thermograph nearby registered for the air. The records from November 12 to April 20 showed a variation in temperature from +13 to −25°C., for the air, +10 to −6°C. at four inches depth, and +8 to −6°C. at eight inches depth. On 93 out of the total of 160 days for the period the ground was covered with snow. The extremely low temperatures in each case followed periods of snowfall so that it is probable that even the material on the surface was not exposed to as low temperatures as were recorded.

Before burying the leaves in the fall, viability tests gave over 95 per cent germination of the spores. Several attempts failed entirely to isolate the fungus from the spot tissues where the mycelium appeared to be dead. This was an unexpected result, which was not fully understood until the following summer. Then it was found that the mycelium could frequently be killed by drying freshly collected leaves quickly in the sun. Thus unfortunately this test was limited to the conidia alone. Little

difficulty was experienced in isolating the spores for germination tests during the early winter, but later, as the cheese cloth and leaf tissue disintegrated, the conidia were more difficult to find. On December 11, 1915, tests of 40 to 50 spores from each level gave 80 to 90 per cent germination. At no time was there any evidence of the formation of new spores and cultures from the spot tissue developed only saprophytic invaders as Mucor, Fusarium, Penicillium, and *Alternaria fasciculata.*

On April 17, 1916, the final examinations were made with the following results:

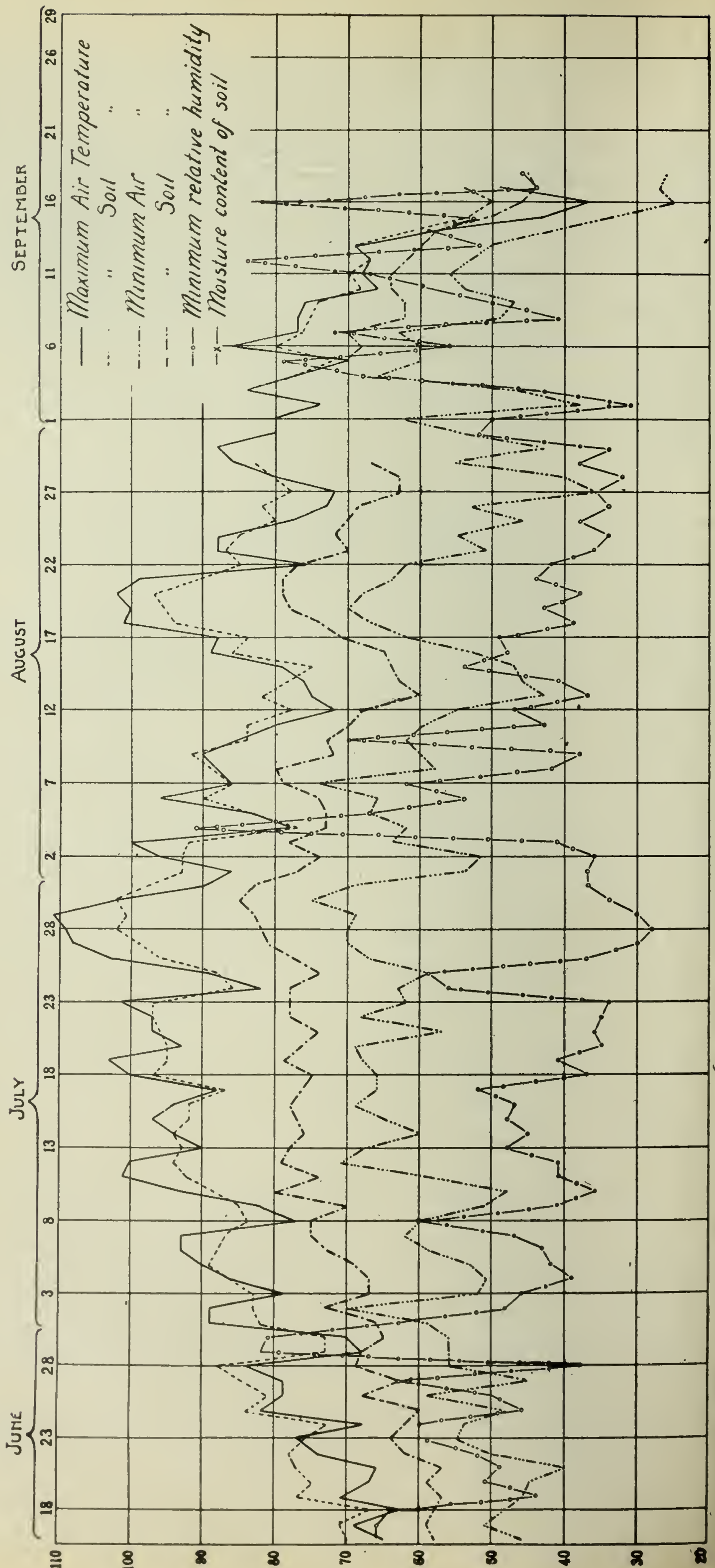
(1) Spores overwintered on the surface—2–3 per cent germination
(2) Spores overwintered at 2-inch depth—40 per cent germination
(3) Spores overwintered at 4-inch depth—50 per cent germination
(4) Spores overwintered at 8-inch depth—65–70 per cent germination

The low figure for the surface germination would probably have been higher had not the location for the plot been selected on low ground where excessive water and ice made conditions unusually severe.

From this experiment it seems justifiable to conclude that a relatively large proportion of the abundant spores produced during the moist weather of late autumn remain viable throughout the winter. The primary infections of the next year doubtless come from such spores which have overwintered in the soil. It is easy for these to reach the lower leaves which are indeed often in immediate contact with the soil, and it is noteworthy that the primary infections always occur on such low lying leaves. This theory is in further accord with the observed fact that early blight starts earliest and is worst on old garden soils and suggests the conclusion that crop rotation is a factor in its control.

THE RELATION OF CLIMATE AND SOIL TO THE DISEASE

Climatic factors undoubtedly exert a great influence upon the dissemination and destructiveness of early blight. As to the climatic conditions best favoring an attack of this disease, Jones (1895) finds that hot, dry weather followed by a moist period is best. Rolfs (1898), in Florida, reports that the disease on tomatoes spread with "alarming rapidity" during moist, warm seasons, while dry, cool weather retarded its progress. Lutman



Maximum Air Temperature
" Soil "
Minimum Air "
" Soil "
Minimum relative humidity
Moisture content of soil
June
July
August
September
18
23
28
3
8
13
18
23
28
2
7
12
17
22
27
1
6
11
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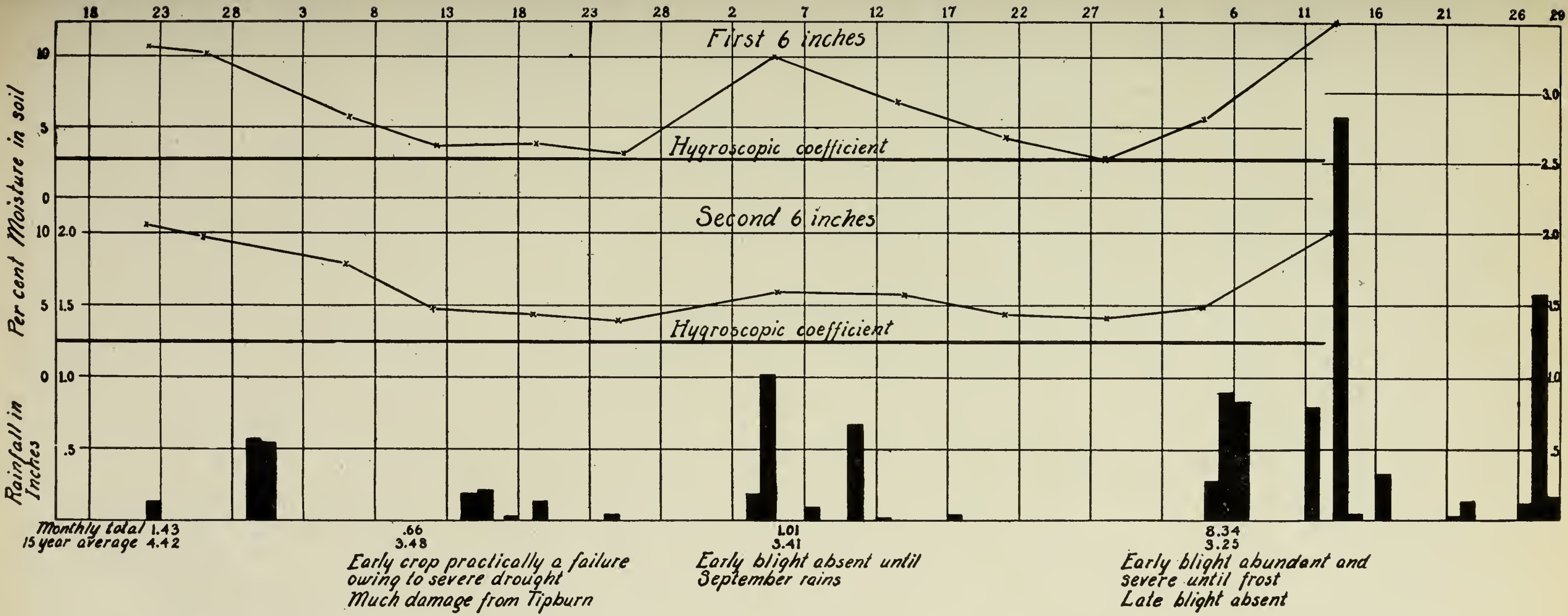

FIG. 10.—CORRELATION OF ENVIRONMENTAL FACTORS WITH EARLY BLIGHT AT WAUPACA, WISCONSIN, 1916

The curves at the top of the chart represent continuous meteorological records taken in the exeprimental field, the air temperature and relative humidity being obtained in a standard Weather Bureau shelter at the same height as the plants and the soil temperature at 3 inches depth among the roots.

As is indicated by the graphs the season was characterized by abnormally high temperatures low humidities, and a deficiency of rainfall. There is evident a close correlation between these various physical factors. e. g., precipitation, available soil moisture, temperature, and humidity. Their influence upon the host plant and the parasite is indicated.

(1911) summarizes twenty years' observation (1891–1910) made at the Vermont station mainly on the relation of the weather to late blight but including data on early blight and tip-burn as well. A careful study of the twenty diagrams and notes presented shows so much contradictory evidence on the occurrence of early blight that few conclusions are possible. His statement that it is a disease of the drier seasons is fairly well corroborated by the diagrams.

Various writers have called attention to the greater destructiveness of this disease on the lighter, sandy soils as compared with the damage it does on the heavy ones. On account of the very generalized nature of our knowledge of this subject, the author has attempted to get evidence which would more clearly show the influence of climatic and soil factors on the severity of the disease. For this purpose continuous meteorological records (air humidity and temperature) were obtained in a standard Weather Bureau shelter at the same height as the potato vines for the seasons of 1915 and 1916. Soil temperatures among the roots and soil moisture determinations were obtained only for the summer of 1916. The light, sandy soil on which the experimental plot was located both seasons, proved ideal for such studies on account of the more decisive response of the plants to changes in environmental conditions. Fortunately for this study the two summers represented extremes in opposite directions from the normal in regard to the conditions favorable for the disease. The season of 1915 was characterized by much wet, cloudy weather during July and early August and by relatively high temperatures. The remainder of August and the first week of September were dry and clear, and normal in temperature. The disease was first noted July 3 on the early crop planted April 25 to May 10, but did little damage prior to the third week in July when the plants began to set tubers. From this time on through August it spread with great rapidity and together with tip-burn resulted in an estimated loss of 35 to 50 per cent. A heavy frost on August 27 and a subsequent severe attack of late blight resulted in considerable loss to the late crop, which had shown but little early blight.

The season of 1916 began with a very wet, cold June with excessive rainfall making conditions unfavorable for the planting and growth of the crop. The first ten days in July were marked

by mild favorable weather after which a period of dry weather with extremely high temperature began and continued almost unbroken throughout the summer until September 5. On twenty days of this period the temperature at the height of the plants reached or exceeded 90°F., and on fifteen days the thermometer registered 100°F or more. On June 26, spots could be found on occasional lower leaves of most of the early fields examined but the vines were very vigorous and were just beginning to flower. By the time the hot weather began, the second week in July, the disease had made but little headway. The high temperature of air and soil and consequent reduction in the available soil moisture now quickly weakened the plants, thus making ideal conditions, so far as host susceptibility was concerned, for the rapid spread of early blight. By July 30, the vines were mostly dead from tip-burn and but very few early blight spots could be found.

The late crop, planted between June 1–15, escaped very largely the severe drought. The rainy weather of September and early October, however, enabled early blight to spread so that 30 to 40 per cent of the foliage was badly diseased. This injury, in connection with two light frosts, operating on the already much retarded plants, it is believed, was an important factor in reducing the tuber yield.

The meteorological records for 1915, being incomplete, are not given. The data summarized in Figure 10* cover, therefore, only the season of 1916. When these are considered in connection with the spot history records (Tables III and IV), made during the same period, there is evident a very close correlation between the various environmental factors and the occurrence and development of early blight. The evidence shows, (1) that in order to have the optimum conditions for an epidemic there must be relatively high temperatures in combination with a more or less weakened condition of the plant so that the fungus can make its greatest spread; (2) that such development will not occur unless the above conditions are prefaced by relatively moist periods of high humidity and abundant dew or rainy weather when spore production and infection can readily take place. The season of 1915 represented just such a correlation of conditions for the early crop. In 1916, on the contrary, no such optimum climatic combination prevailed, so that, although the

*The writer is indebted to Prof. H. W. Stewart of the University of Wisconsin, who determined the moisture equivalents from which the hygroscopic coefficients (approximate nonavailable moisture) were calculated.

plants were in a most susceptible condition, there was no general occurrence of early blight until late autumn.

These studies suggest a possible explanation of the severity of this disease in some countries and its practical absence in others. While the writer has had no opportunity personally to observe it in other countries it is noteworthy, according to reports in literature, that the organism occurs in practically all important potato growing regions of the world. The difference in destructiveness, therefore, must be due, not to the lack of introduction, but to a difference in climatic conditions. As already noted it is reported more severe in the United States, Australia, New Zealand, and South Africa than in Europe. Conclusions from studies in Wisconsin seem to indicate the following interpretation: the disease is more destructive in the first countries named because in general the average summer temperatures of these regions are not only higher but probably subject to greater fluctuations and extremes which, combined with variations in rainfall, make conditions less favorable for the growth of the plant. In central Europe, on the contrary, where early blight as a serious disease is practically unknown, the moderately low summer temperatures and the uniformally distributed rainfall furnish highly favorable conditions for the host plant, while less favorable for the best development of the parasite.

CONTROL MEASURES

RESISTANT VARIETIES

Stuart (1914) summarizes the results of five years' observations of the relative resistance to early blight of 153 American and foreign varieties of potatoes. Four of the ten varieties found most resistant to early blight are also found among the ten most resistant to late blight. But one of the ten was of American origin and it was of no commercial importance. The European varieties, though quite resistant, did so poorly under our climatic and soil conditions as to be practically worthless from a commercial standpoint. He concludes: "the value of the disease resistant varieties is problematical rather than actual. The plant breeder, by mating them with the most desirable commercial types, may develop commercial types of resistant varieties." Green and Waid (1906) of the Ohio station,

however, believe that much can be done in building up resistant varieties by selecting seed from resistant hills.

The McCormick variety is said by Norton (1906) to show decided resistance to early blight. Prof. T. H. White of the Maryland station furnished the writer with seed of this variety which was tried out in 1915 and 1916 in Wisconsin. The unusually large coarse vines showed by far the greatest resistance compared with the fifteen other varieties grown. However, in late September, 1915, when the stage of greatest vigor had passed, they also showed 20 to 30 per cent of the foliage badly diseased. The poor quality of the tuber will probably prevent it from becoming of much commercial importance where more desirable varieties can be profitably grown.

SPRAYING

The early spraying trials by Jones, aimed particularly at early blight (see Jones and Morse 1905), as well as the long series of potato spraying experiments at the New York and Connecticut stations, have shown the practical control of this disease with bordeaux mixture. Lutman (1911), summarizing the twenty years' spraying in Vermont, states that three to four applications of the 5–5–50 bordeaux "efficiently protects the plants from the attacks of the early and of the late blight." Milward (1909) states that increased yields result from spraying in Wisconsin when not less than four applications are given and the spraying commenced not later than August 15.

Stewart (1914) states that in the ten year series at Geneva there was an average increase from spraying for both blights of 97.5 bu. per acre. The 4–4–50 formula is recommended for the first two applications with an increase to 6–4–50 in the late sprayings. On the other hand Clinton (1916) obtained an average increase of 38 bushels per acre in Connecticut with three applications of the 4–4–50. Additional evidence bearing directly on the control of early blight is given by Jack (1913 and 1916) for Rhodesia in South Africa. There early blight appears to be by far the most important disease of the potato. Several years results showed an increase in yield, due to spraying with bordeaux mixture, ranging from 16 to 57 per cent.

Wherever this disease causes practical injury on the tomato, spraying with bordeaux mixture has also been recommended.

Edgerton and Moreland (1913) advise one application in the cold frame and one every ten days thereafter in the field if the disease is prevalent.

The spraying experiments conducted by the writer were designed primarily to furnish evidence on control correlated with his life history studies of the fungus, and secondarily to test out under Wisconsin conditions the recommendations of workers in other states.

SPRAYING EXPERIMENTS AT WAUPACA

The season of 1915 was unusually favorable for the development of early blight. Spraying was done, however, only on the late crop which, in the experimental plot, was completely killed by frost on August 26 before much differentiation between sprayed and unsprayed was noticed.

In 1916 both early and late potatoes were sprayed, but unfortunately for the experiments on early potatoes, little disease occurred this season. In spite of this the results obtained seem worthy of record. On the late crop, planted between June 5 and 15, it operated in weakening the already much retarded vines and was undoubtedly responsible for a large part of the shortage in yield.

On early potatoes—Experiments were undertaken in two gardens which had grown several successive crops of potatoes and in which early blight had been noted as severe in 1915. The plots were sprayed by hand with a modified Hudson and Thurber compressed air sprayer. This pump proved quite satisfactory for plots of small size and, with high pressure, gave a very fine spray. Great care was taken to cover all leaves thoroughly with the mixture. The amount applied each time was determined by the differences in gross weight of the container before and after spraying. As a rule about 150 gallons per acre were used for each of the first two applications, and 175 to 200 gallons per acre for the later sprayings. Since early blight was a negligible factor on account of the extreme drought, the beneficial results obtained are attributable primarily to the lessening of tip-burn and flea beetle injury. However, it is noteworthy that, whereas a dozen or more spots developed on each control plant in Plots 1 and 3 (Experiment B), only rarely

could an infection be found on Plot 2, which received weekly applications (9 in all). beginning when the plants were 6 inches high. The results are combined in Table V.

Table V.—Spraying Experiments on Early Potatoes

Experiment A, Van Patten Garden; Six Weeks Variety

Plot	Treatment	Yield				Increase	
		Actual number lbs.			Bu. per A.	Bu.	Per cent
		Large	Small	Total			
1	Bordeaux 5-5-50 June 16, 24; July 1, 8, 15, and 29	42.5	15.0	57.5	87.0	4.5	5.2
2 Control	Paris green and lime	38.0	11.0	49.0	82.5		
3	Bordeaux 5-5-50 July 1 and 15	45.5	8.5	54.0	90.8	5.3	5.8
4 Control	Paris green and lime	47.5	7.5	55.0	84.4		
5	Bordeaux 5-5-50 July 1, 10, and 29	56.0	11.0	67.0	107.6	19.3	17.9
6 Control	Paris green and lime	23.75	3.75	27.5	88.3		
7	Bordeaux 5-5-50 July 8. 18, and 28	77.0	12.0	89.0	144.0	38.8	26.9
8 Control	Paris green and lime	55.5	10.0	65.5	105.2		
9	Bordeaux 5 5-50 June 24: July 8 and 22	53.0	12.5	65.5	104.4	17.1	16.3
10 Control	Paris green and lime	43.5	12.5	56.0	87.3		
11	Bordeaux 2-4-50 June 24: July 8 and 22	43.5	17.0	60.5	92.3	—2.3	—2.4
12 Control	Paris green and lime	46.5	15.5	62.0	94.6		

Experiment B, Taylor Garden; Early Denver Variety

Plot	Treatment	Large	Small	Total	Bu. per A.	Bu.	Per cent
1 Control	Paris green and lime	38	27.5	65.5	112.2		
2	Bordeaux 5-5-50 June 16, 24: July 1, 8, 15, 22, 29: Aug. 5 and 14	41	29.5	70.5	120.7	17.5	14.5
3 Control	Paris green and lime	15.5	12.0	27.5	94.2		

On late potatoes—In experiments A and C (Table VI) the spraying was done on selected rows in one tenth acre plots which had been cropped successively to potatoes for several years. These were sprayed in the same manner as the early potatoes. The other trials were carried out on various farms near Wau-

paca, where the fields had been subjected to a four year rotation. Here an upright barrel outfit on a cart was employed.

Though much retarded in development the late potatoes escaped to a large extent the severe drought during July and August. Revived by the heavy rains in September they made good growth, and, had frost held off until late October, a fair yield could have been obtained. The entire plot in Experiment A was heavily watered with a hose several times during the early part of the season, which fact accounts partly for the greater amount of disease and the consequent greater difference in yield as compared with the other experiments. This plot also received the greater number of sprayings. Prior to September 13, early blight was practically absent in any of the fields except Experiment A. The rains and favorable weather following this date permitted rapid spread of the disease on the already weakened plants. Thus during a month of favorable growing weather for the plants a good portion of the leaf area in most cases became badly diseased. Flea beetles and tip-burn were practically absent and no late blight was found. In all these experiments those rows which received two or more applications of the 5–5–50 bordeaux contained in every case larger and more vigorous plants even before any disease occurred. This seemed to be due entirely to the stimulative action of the spray. The disease was not absolutely controlled in any case, not even plot 1 of Experiment A, which received 7 applications. Several light frosts in September complicated the situation in Experiment B where the sprayed plants on this sandy type of soil showed a striking resistance to frost injury. Aside from this, however, the uniform and consistent increase from the spraying is attributable to but two factors, viz., (1) the practical control of early blight and (2) the stimulative action of the bordeaux mixture on the plants. The results are presented in summary form in Table VI.

RECOMMENDATIONS FOR SPRAYING

While the period during which the foregoing experiments were conducted was not typical of the average year in many respects, yet the intensive study made of the disease in connection with them seems to warrant the following deductions:

For the early crop under Wisconsin conditions the disease can be profitably controlled by four to six applications of the

TABLE VI.—SPRAYING EXPERIMENTS ON LATE POTATOES

Plot	Treatment	Yield: Actual Number lbs. Large	Small	Total	Bus. per A.	Increase: Bus.	Per cent
Experiment A, Turrell field; Rural New Yorker No. 2							
1	Bordeaux 5-5-50 June 28; July 8, 18, 28; Aug. 7, 17; Sept. 6	123.0	10.5	133.5	331.9	144.2	43.4
2 Control	Paris green and lime	60.5	15.0	75.5	187.7		
3	Bordeaux 5-5-50 June 28; July 12, 26; Aug. 9, 24; Sept. 6	107.0	16.0	123.5	301.4	113.7	37.7
Experiment B, Constance field; Rural New Yorker No. 2							
1	Bordeaux 5-5-50 Aug. 12; Sept. 7	188.0	35.0	223.0	111.5	23.0	20.6
2 Control	Paris green and lime	149.0	28.0	177.0	88.5		
3	Bordeaux 5 5-50 Aug. 12, 22; Sept. 7	190 0	31.0	221.0	110.5	22.0	19.9
4 Control	Paris green and lime	133.0	27.0	160.0	80.0		
5	Bordeaux 5-5-50 Aug. 12, 22	167 0	35.0	202.0	101.0	21.0	20.8
6 Control	Paris green and lime	133.0	26.0	159.0	79.0		
7	Bordeaux 5-5-50 Aug. 12, 22; Sept. 7	163.0	38.0	201.0	100.5	21.5	21 4
8 Control	Paris green and lime	140.0	24.0	164.0	82.0		
9	Bordeaux 5-5-50 Aug. 12; Sept. 7	149.0	34.0	183.0	91.5	9.5	10.4
10	Bordeaux 5-5-50 Aug. 12, 22; Sept. 7	152.0	31.0	183.0	91.5	9.5	10.4
Experiment C, Taylor field; Rural New Yorker No. 2							
1	Bordeaux 5-5-50 July 8, 22; Aug. 5, 17; Sept. 13	83.0	18.9	104.9	190.5	74.7	39.2
2 Control	Paris green and lime	46.9	16.9	63.8	115.8		
3	Bordeaux 2-4-50 July 8, 22; Aug. 5, 17; Sept. 13	38.5	18.1	56.6	102.7	18.5	18.0
4 Control	Paris green and lime	28.3	18.1	46.4	84.2		
Experiment D, Pinkerton field; Rural New Yorker No. 2							
1	Bordeaux 5-5-50 Aug. 12; Sept. 7	250.5	95.0	345.5	93.9	13.9	13.7
2 Control	Paris green and lime	198.5	98.0	296.5	80.0		
3	Bordeaux 5-5-50 Aug. 22; Sept. 7	299.5	81.0	380.5	103.4	27.7	26.7
4 Control	Paris green and lime	197.0	66.0	263.0	71.5		
5	Bordeaux 5-5-50 Aug. 22; Sept. 7	229 5	80.5	310.0	84.3	8.6	10.2

standard 5–5–50 bordeaux mixture. Complete control can only be attained by weekly sprayings begun when the plants are six to eight inches high and continued through the remaining period of growth.

For the late crop, the results indicate that the three to four applications ordinarily recommended for the control of late blight will also largely control early blight.

Thoroughness of application cannot be overemphasized in spraying for early blight.

SANITATION

From the evidence already presented that primary infection results from spores overwintering in the soil, and from observational data on the persistence of the fungus in dead vines, it is clear that in certain cases sanitation becomes an important factor to be considered. Crop rotation is of course the rational measure and in those cases where it is desired to crop the land continuously to potatoes, all dead vines should be raked together and burned immediately after harvest. Such measures will tend to reduce the number of primary infections but they should be regarded merely as contributing to the success of the more certain method of control, viz., spraying.

SUMMARY

Early blight, *Alternaria solani* (E. & M.) J. & G., of potato and related plants is a characteristic leaf spot disease distinguished by the concentric markings or "target-board" appearance of the spot.

This disease is practically world wide being found wherever the potato is an important crop, but it is of economic importance in but few countries, especially the United States, Australia, New Zealand, and South Africa.

The damage from this disease is indirect, i. e., it causes the premature death of the foliage and this results in decreased yields. During some years early blight does more damage than late blight but it is the annual small loss which makes it a serious obstacle to successful potato culture. On the tomato, where it causes spotting of both leaves and fruit, Edgerton and Moreland, 1913, place it next to wilt in importance.

Early blight, in Wisconsin, occurs commonly on potato, tomato and eggplant. The identity of the fungus on these hosts has been established by morphological and cultural studies and by reciprocal cross inoculations from single spore cultures. The

leaf spot of Jimson weed (Datura) which has been widely attributed to the same fungus, is shown to be due to a similar but distinct species of Alternaria which was early described by Saccardo as *Cercospora crassa*. For this the author has given the new combination *Alternaria crassa*.

To determine the host range of the fungus, inoculations were made under field conditions on 30 species and varieties of the family Solanaceae. On 29 of these penetration and incipient infection occurred. However, the fungus was able to complete its life cycle on but 12 of the plants, which in addition to two others not included in the tests, make its known host range 14 species and varieties representing the genera Solanum, Lycopersicon, Nicandra, and Hyocyamus.

The early blight fungus was first described in 1882 and named *Macrosporium solani* Ellis and Martin. Jones and Grout, 1896, and Sorauer, 1896, changed the name (the latter on insufficient evidence) to *Alternari solani*. Though the writer has never observed conidia in chains in nature and they occur but rarely in culture, the present uncertain taxonomic relationship of the two genera, Alternaria and Macrosporium, and the established usage leads him to provisionally retain the latter binominal, *Alternaria solani* (E. & M.) J. and G.

The important diagnostic characteristic of the fungus is the long, single or forked, terminal beak of the conidium.

On potato and other vegetable and fruit extract agar, the colony produces a brilliant yellow pigmentation of the medium, later becoming reddish.

After repeated trials to obtain spores in culture, it was found that by stirring or shredding the agar and mycelium in the petri dish and carefully regulating the moisture for 24 hours abundant sporulation could be secured. This served as the source of material for spore germination and inoculation studies.

The cardinal temperatures for spore germination and mycelial growth on favorable media fall within the following limits: minimum 1–3°, maximum 37–45°, optimum 26–28°C. Five to ten germ tubes emerge at the optimum while at the minimum usually not more than half this number develop.

Spore production in nature may begin when the spot has reached a diameter of 3 to 4 millimeters. A given spot may produce 1500 to 3000 spores in two to three successive crops during a season.

The conidia are readily dislodged from their conidiophores, and local dissemination appears to be chiefly effected by wind and rain. Colorado potato beetles may also spread the disease.

Infection may occur via the stomates or directly through the cuticle.

The period of incubation varies from 48 to 72 hours.

Primary infection may result from overwintered conidia or possibly from new conidia produced by overwintered mycelium.

Though conidia were found to overwinter on leaves on the surface of the ground, the proportion surviving the winter was greater on those buried at 2, 4, and 8 inch depths.

Early blight ordinarily makes little development until the host has passed its period of greatest vigor and is being weakened by external conditions or by the drain of tuber formation. Optimum spore production is dependent upon frequent rains aided by heavy dews. Climate and soil exert a controlling influence upon the development of the disease. In general it becomes most serious when the season begins with abundant moisture which is followed by high temperatures unfavorable to the host plant but with sufficient moisture to insure maximum sporulation. Periods of continued drought check its spread completely. The conclusion is, therefore, reached that the optimum conditions for an epidemic of early blight require relatively high temperatures alternating with moist periods in combination with a more or less weakened condition of the plant.

The unusual resistance of the McCormick potato to early blight, reported by Norton, 1906, has also been observed by the writer, but unfortunately this variety is a poor commercial type. The possibility of securing resistant varieties with the best commercial qualities has been shown by Stuart, 1914, to offer little immediate encouragement, but he is continuing breeding experiments with this in mind.

Sanitary measures are recommended based on the evidence as to the overwintering and origin of primary infections. These include crop rotation and the destruction of the dead potato tops in gardens where continuous cropping is practised.

Spraying experiments conducted by the writer confirm the results of others and show that timely and thorough spraying with home made bordeaux mixture profitably controls early blight. (See summarized recommendations for spraying, p. 42).

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The Milling and Baking Qualities of Wisconsin Grown Wheats

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CONTENTS

APPENDIX.

The Milling and Baking Qualities of Wisconsin Grown Wheats

In the pioneer days of Wisconsin, wheat was the most important crop grown. The climate was favorable, settlers had emigrated largely from wheat growing regions, the yields were uniformly high and the quality was considered excellent. Wisconsin's fame as a wheat state spread and in the early Sixties she was one of the leading wheat states of the Union.

The varieties were all soft, such being considered the best milling wheats in the days of stone milling. However, with the advent of the roller milling process in the Seventies, the hard spring wheats replaced the soft wheats in desirability for milling purposes. About this time the hard winter wheat was introduced from Russia but it was slow in gaining favor. It was not considered the equal of the hard springs in milling quality, and when taken to regions where there was considerable moisture during the growing season it seemed to soften appreciably. However, winter hardness and high yields were so outstanding in these Turkey Red wheats that they continued to be grown.

In Wisconsin three climatic wheat areas overlap—the hard spring, the hard winter and the semi-hard winter. At first glance this would indicate a peculiarly favorable location wherein varieties could be chosen from all of the three groups. However, the opposite is true. As wheat is very sensitive to its environment, only a limited number of varieties which have the power of rather wide adaptation can be expected to produce the best results under such conditions.

Semi-hard winter wheats thrive in Wisconsin but the breadmaking quality of these wheats is decidedly inferior to the hard winters and the hard springs. The hard winters seem to offer the best field for practical research. While the general tendency is for these wheats to become starchy when grown in this state yet some strains are decidedly superior to others in their ability to remain hard. The problem, therefore, is to determine

the most desirable varieties from the standpoint of yield and quality and to discover as far as possible what fluctuations in quality may be expected of varieties when grown in this state.

IMPORTANT FACTORS WHICH DETERMINE MILLING AND BAKING QUALITIES OF WHEAT

Flour yield and color. From the milling standpoint the important items are flour yield and flour color.

The desideratum is a high percentage of flour of white color with a faint creaminess. Yield is the quantitative factor and shows the miller the amount of the most valuable mill product he can expect from the wheat. The color is the qualitative factor which largely determines the grade of the flour.

Loaf volume. The volume of the loaf as determined by the baking test is the most important and most easily recognizable factor which determines flour values for bread making. It indicates the ability of the flour to expand, to hold up well, and to give a light, well-piled loaf.

Texture of loaf. As volume of loaf is the quantitative factor, so texture of loaf is the qualitative factor which is determined by the baking test. It is more difficult to express readily because it entails such items as uniformity, number and evenness of distribution of cavities, and thinness and transparency of the walls between the cavities.

Water absorption. The same amount of ingredients, except water, is used in each case in mixing the dough for the baking test. Enough water is added to make the proper consistency. This added water is taken as the measure of the absorption power of the flour. The weight of the loaf as it comes from the oven shows its ability to hold the absorbed water. High water absorption and retention after baking makes a good bread yield to the barrel of flour.

Gluten. The amount of gluten is often taken as an indication of the flour strength, but only within rather wide limits can this be used. The quality of gluten, however, is a very important factor, because without an elastic, rubbery, more or less tough gluten, proper expansion will not result. The distinctions

between different glutens that can be noted by working them out by hand are difficult to express and written comparisons are rather indefinite.

A Review of the Literature on Milling and Baking Tests of Hard Winter Wheats

Milling and baking tests of wheat have been made by nearly all stations in states where wheat growing is important. As climatic conditions seem to play such an important part in the kind and quality of wheat grown in the different wheat growing regions, each section ha sits own peculiar wheat problems.

A brief review of some of the literature is given here to show the results of some tests of Turkey Red wheats when grown outside of the regions best adapted to them.

Zavitz[1] mentions the Crimean Red and Kharkov, evidently two types of the Turkey wheats, as making a very favorable showing in a five-year-average yield test. In bread production, only the Crimean Red is mentioned as having superior qualities.

Williams and Welton[2] in a test of 41 varieties of wheats in 1909 find the Turkey Red lowest in flour yield and very mediocre in loaf volume.

Ladd and Bailey[3] report tests made in 1908 of Turkey wheat grown in North Dakota, Minnesota, South Dakota, and Montana, and comparisons are made with the hard red winter wheats grown south of the forty-second parallel. The sample grown in North Dakota gave the lowest percentage of flour, water absorption, loaf volume, and color. The average of the samples grown south of the forty-second meridian was higher than those grown in the above-mentioned states in total flour, volume of loaf, color of loaf and crude protein. The water absorption was about the same.

A series of tests made in 1909 shows the "hard winter wheats grown in the Northwestern states to have been inferior to the average wheat of this class in point of baking quality, although the average yield of straight flour was very good." However, one sample grown in South Dakota was appreciably higher than the others in volume of loaf, water used, and percentage of pro-

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[1] Ontario Bul. 228.
[2] Ohio Bul. 231.
[3] North Dakota Bul. 89.

tein, and was far above the average of all hard winter wheats. "Environment, including soil and climatic conditions is principally responsible for the variations in quality."

Thomas,[1] in comparing classes of wheats for milling and baking qualities, shows that the hard red winter wheats compare very favorably on the whole with the hard red springs. "Over 90 per cent of the samples of soft red winter and hard red spring wheat yielded between 65 and 75 per cent of straight flour. The hard red winter samples ranged somewhat higher, as over 90 per cent yielded between 67 and 77 per cent of straight flour. In average flour yield hard red winter wheat is about 2 per cent higher than the other classes."

In color of flour there was a little higher percentage creamy color in the hard red winter varieties than in the hard red springs. The range of color was about the same.

In loaf volume the ordinary range of the hard red winter wheats was somewhat lower than that of the hard red springs. To quote: "The ordinary range for hard red winter was from 2000 to 2500 cc. and for the hard red spring wheat 2100 to 2700 per 340 grams of flour. The extreme ranges in loaf volume as indicated by maximum and minimum are 1810 to 2755 cc. for the hard red winter and 1875 to 3260 cc. for the hard red spring wheat. The figures show great variation which is the result of growing these wheats under a wide range of conditions of soil and climate. In a general way the data gathered from year to year indicate that unfavorable climatic conditions during the later part of the growing season tend to produce the strongest wheats."

In texture the comparison between the hard red winter and hard red spring was closer than in loaf volume.

In water absorption the hard red winter averages slightly lower than the hard red spring wheats.

The range of variation in the tests reported shows a wide difference between samples. A rather small percentage of the hard red winters rank very high in all tests, far above the average of the hard red springs. In flour yield and color a few of the very highest hard red winters rank with the few highest of the hard red springs.

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[1] U. S. Dept. Agr. Bul. 557.

A review of the results of the experiments on Turkey Red wheats indicates two things:

1. They are susceptible to climatic changes and do not give best results when grown outside of the dry, warm climates.
2. The wide variation shown between samples in the milling and baking tests suggests a difference in the inherited qualities which make good bread wheats.

METHOD OF PROCEDURE

In 1911, when the writer began the study of wheat improvement at the Wisconsin station at Madison, several very good yielding strains of winter wheat had been pedigreed. Several spring wheat strains were introduced about this time from Minnesota and Dakota.

To select the most desirable strains, milling and baking tests were made to determine quality in addition to the usual study of field performance. After a two-year test several eliminations were made. New introductions of several excellent hard winter wheats were made in 1911 from Kansas and from some of the best yielders of Ontario. Later seven of the most popular wheats were introduced from the Purdue station. These were semi-hard varieties and only a limited number of such wheats were given a milling and baking test.

The main line of effort in the milling and baking studies was centered on the hard winter wheats to see if some strains could be found which would overcome the objections to hard wheat grown in Wisconsin. Some spring wheats were included in these tests, but it soon became evident that the spring wheat yields were so low that they would not be able to compete equally with winter wheats. However, the Marquis, the best yielder among the springs, was continued throughout the series of tests as a basis for comparison. The semi-hard and soft varieties were also entered primarily for comparison.

Owing to the cost of milling and baking many of the poor yielders were discarded without this additional test. As other varieties appear only once or twice in the reports, a considerable portion of the work is discontinuous.

Another change in the original plan was made when it be-

came evident that good milling wheat could be raised in Wisconsin. The work was then broadened to include other related studies having a bearing on quality.

Four lines of investigation are presented:

1. To determine by milling and baking tests the desirable varieties.
2. To determine how well hard winter wheat will maintain its milling and baking qualities when grown continuously in Wisconsin.
3. To determine if heritable variations in quality between pure lines are great enough to have practical significance.
4. To determine how deleterious from the milling and baking standpoint, the yellow berry is in hard winter wheats.

The Howard Wheat and Flour Testing Laboratory of Minneapolis made all the milling and baking tests with the exception of one year. In 1914, the Bay State Milling Company of Winona, Minnesota, kindly offered the Wisconsin Experiment Station the use of its laboratory. The writer was glad to take advantage of this offer and assist in the tests. This afforded the apportunity of making a detailed comparative study of the products. The Department of Milling and Baking of the Kansas Experiment Station made the comparative milling and baking tests of the Kansas-grown and Wisconsin-grown wheats in 1913.

MILLING AND BAKING TESTS TO DETERMINE THE DESIRABLE VARIETIES

Forty-eight varieties and strains of wheat were tested for milling and baking quality in the seven years that this experiment was carried on. Hard spring wheat, semi-hard and soft varieties of winter wheats and a soft spring variety were included in the test. Names of the varieties can be found by referring to Table XVIII. As some of these were carried on for a very short time before being discarded, it was thought inadvisable to load the tables and discussion with this discarded material. The complete reports on the milling and baking tests are reproduced in the appendix. The most important data in these tests are summarized in the following tables.

SOME PROMISING TESTS CARRIED THROUGH 1911, 1912, 1913

Hard winter wheats, Pedigrees No. 2, 11, 21, 6 and 22 were close competitors in the initial tests. These were given a three-year test and eliminations made as inferiority became evident in either yield or milling and baking quality. The comparative results for the three years are given in Table I.

TABLE I.—A COMPARISON OF THE FIVE BEST PEDIGREED WINTER WHEATS CARRIED THROUGH THE THREE-YEAR TEST—1911, 1912, 1913

Name	1911	1912	1913	Average	Rating (Ped. No. 2=100 per cent)
Volume of loaf					
Ped. No. 2	203	196	....	199.5	100
Ped. No. 11	199	175	....	187.0	95
Ped. No. 21	198	201	....	199.5	100
Ped. No. 6	196	195	....	195.5	98
Ped. No. 22	204	186	....	195.0	98
Yield of flour					
Ped. No. 2	74.5	74.8	....	74.65	100
Ped. No. 11	74.8	73.4	....	74.1	99.2
Ped. No. 21	76.8	74.7	....	75.75	101.4
Ped. No. 6	73.0	74.8	....	73.9	98.9
Ped. No. 22	75.3	74.9	....	75.1	100.6
Protein in wheat					
Ped. No. 2	12.36	12.08	15.82	13.42	100
Ped. No. 11	11.68	10.45	14.47	12.20	91
Ped. No. 21	10.61	11.17	14.82	12.20	91
Ped. No. 6	11.79	11.04	14.47	12.43	92
Ped. No. 22	10.69	10.98	13.88	11.85	88
Dry gluten tests					
Ped. No 2	....	10.83	12.8	11.81	100
Ped. No. 11	....	9.79	11.6	10.70	91
Ped. No. 21	....	10,00	12.0	11.00	93
Ped. No. 6	....	9.58	11.2	10.39	88
Ped. No. 22	....	10.21	11.8	11.00	93
Yield per acre					
Ped. No 2	21.6	38.3	45.0	35.0	....
Ped. No. 11	34.0	28.3	42.6	35.0	....
Ped. No. 21	27.3	34.3	47.3	36.3	....
Ped. No. 6	23.3	30.3	43.0	32.2	....
Ped. No 22	26.6	29.0	46.3	34.1	....

Pedigree No. 2 and No. 21 give the largest loaf volume. In yield per acre Pedigree No. 21 is slightly highest but the difference between it and Pedigree No. 2 and Pedigree No. 11 is within the limits of error. In flour yield Pedigree No. 21 is slightly ahead. In per cent gluten and protein in wheat, Pedigree No. 2 was appreciably higher. Pedigree No. 2 and No. 21 having the highest averages for both quality and yield are selected from this lot for further test, and the other varieties discarded.

MILLING AND BAKING TESTS OF WHEAT GROWN ON DIFFERENT TYPES OF WISCONSIN SOILS

An opportunity was afforded in 1914 to test some of the station-grown wheats on a light sandy soil in Waupaca county and upon the Kewaunee clay loam of Fond du Lac county. Pedigree No. 2 and No. 37 winter wheats were grown on the Miami silt loam of the station farm and also upon the Kewaunee clay loam in Fond du Lac county. Table II gives the results of the test.

TABLE II.—MILLING AND BAKING TESTS OF WHEAT GROWN ON DIFFERENT TYPES OF WISCONSIN SOILS IN 1914

Name	Soil	Flour				Loaf			Gluten per cent
		Per cent yield	Color	Per cent absorption	Ash	Vol. cu. in.	Water used ounces	Quality	
Ped. No. 2	Miami silt loam	65.2	9 9	61.5	.50	148	6.85	Little creamy... Rich crust Very good quality	10.57
Ped. No. 2	Kewaunee clay loam	63.6	99	62.5	.42	150	7.03	Little creamy.. Rich crust Very good quality	11.51
No. 37.......	Miami silt loam	64.5	97	61.0	.36	139	6.85	Soft dough....... Very pale crust Fair quality	9.69
No. 37.......	Kewaunee clay loam	62.5	96	58.0	.44	137	6.49	Soft dough....... Pale crust Poor quality	8.55
Ped. No. 21	Sandy soil	61.1	99	62.0	.32	150	6.97	Little creamy... Rich crust Excellent quality	10.57
Ped. No. 21	Kewaunee clay loam	62.7	98	62.0	.34	145	6.97	Very creamy.... Rich crust Good quality	9.88

In volume of loaf, quality of loaf, water absorption, and color of flour no consistent differences appear. The Pedigree No. 2 gives a slightly better test when grown on the Kewaunee clay loam while the No. 37 makes a slightly better showing when grown on the station farm.

Pedigree No. 21 was grown on the Kewaunee clay loam and

upon the sandy soil of Waupaca county. The test shows no striking differences. The clay gives a slightly higher flour yield and percentage of ash. The crop grown on sand gave better color of flour, more gluten, and an appreciably larger loaf of better quality.

From this test we can conclude that wide variation in quality need not be expected in wheat, whether grown on heavy clay or light sand. This is the only indication of what quality may be expected from wheat grown in eastern or central Wisconsin, as the other tests herein reported for the different years were made on wheats grown at the Station farm.

LOAF VOLUME

Table III shows a comparison in loaf volume of the wheats given a two- or a three-year test in 1915, 1916, and 1917. In 1915 Pedigree No. 2 gave the largest loaf in all the tests made. It will be noted that it leads the Marquis (No. 50) on a three-year average. No. 70, a Turkey wheat, exceeds it on a two-year average.

TABLE III—COMPARISONS IN LOAF VOLUME IN CUBIC INCHES FROM THE BAKING TESTS OF 1915, 1916, 1917.

Name	1915	1916	1917	Av.	No. of years	Rating Ped. No. 2=100 per cent.
Ped. No. 2 Turkey Red	209	183	191	194	3	100
No. 50 Marquis	196	193	187	192	3	99
Ped. No. 408	196	181	182	186	3	96
No. 39 Turkey Red	203	154	185	181	3	93
No. 37 Egyptian Amber	160	138	159	152	3	78
No. 55 Farmer's Friend	148	128	160	145	3	75
No. 59 Nixon	136	138	150	141	3	73
No. 70 Beloglina Selection		192	205	198	2	106
No. 71 " "		137	157	147	2	79
Ped. No. 39 Dawson's Golden Chaff		113	130	121	2	65
Ped. No. 37 " " "		110	125	117	2	63

The average of the hard winters (Pedigrees No. 2 and No. 408, No. 39, No. 70, No. 71) is 181 cu. in., of the semi-hards (No. 37, No. 55, No. 59) is 146 cu. in., of the soft winters (Pedigrees No. 37 and No. 39) is 119 cu. in.

The per cent rating in these tables is determined from the same year's tests. To illustrate: The comparison of Pedigree No. 2 and No. 37 is made from the average of the three years

1915–1917 which is 194 cu. in. and 152 cu. in. respectively. In comparing Pedigree No. 2 with No. 70 the averages of 1916–1917 are taken, 187 cu. in. and 198 cu. in., respectively.

FLOUR YIELD

In Table IV Pedigree No. 2 rates lower than several others in a three-year average, yet in 1917 it showed a higher percentage than any other hard winter wheat. Pedigree No. 408 is one of the highest in the three-year average, and is very consistent, varying only .2 per cent in flour yield in these years.

TABLE IV.—COMPARISONS IN FLOUR YIELD FROM THE MILLING TESTS OF 1915, 1916 1917

Name	1915	1916	1917	Av.	No. of years	Rating Ped. No. 2= 100 per cent.
Ped. No. 408	73.8	73.8	73.6	73.7	3	101
No. 37 Egyptian Amber	76.8	70.5	73.9	73.7	3	101
No. 39 Turkey Red	72.6	75.0	73.2	73.6	3	101
Ped. No. 2 Turkey Red	70.3	73.8	74.5	72.9	3	100
No. 55 Farmer's Friend	73.9	71.5	72.0	72.5	3	99
No. 50 Marquis	72.5	72.0	72.4	72.3	3	99
No. 59 Nixon	73.2	71.2	71.8	72.1	3	99
No. 70 Beloglina Selection	......	76.5	74.2	75.3	2	102
Ped. No. 39 Dawson's Golden Chaff	......	74.3	75.0	74.6	2	101
Ped. No. 37 Dawson's Golden Chaff	......	72.8	75.2	74.0	2	100
No. 71 Beloglina Selection	......	74.3	73.1	73.7	2	99

The two soft winters average slightly higher in flour yield—74.2 per cent; the hard winters rank next—73.8 per cent; and the semi-hard winters lowest—72.8 per cent. As variations show between these groups in the three-year test it is not safe to conclude that this difference will hold true between the soft, hard, and semi-hard winter groups grown in this section.

GLUTEN TESTS

As has already been stated the quantity of gluten is not a safe guide in determining baking quality in wheats.

Pedigree No. 37 in a two-year average shows slightly more gluten than does Pedigree No. 2 but is very much inferior in size and quality of loaf.

TABLE V.—COMPARISONS IN THE PERCENTAGE OF GLUTEN FROM THE TESTS OF 1913, 1914, 1915, 1916, 1917

Name	1913	1914	1915	1916	1917	Average	Number of years
Ped. No. 2 Turkey Red	12.8	10.57	10.45	10.13	11.2	11.0	5
No. 39 Turkey Red	12.4	11.20	10.	10.31	12.4	11.2	5
No. 37 Egyptian Amber	10.	9.69	10.38	8.06	11.6	9.9	5
No. 50 Marquis	13.6	12.46	13.7	12.25	12.	12.8	5
Ped. No. 408 Bacska	....	11.13	10.36	10.56	13.8	11.5	4
No. 55 Farmer's Friend	....	....	9.78	8.19	11.8	9.9	3
No. 59 Nixon	....	....	10.17	8.44	11.2	9.9	3
No. 70 Beloglina Selection	....	....	....	10.00	13.2	11.6	2
No. 71 Beloglina Selection	....	....	....	9.94	11.8	10.9	2
Ped. No. 37 Dawson's Golden Chaff	....	....	....	11.25	11.2	11.2	2
Ped. No. 39 Dawson's Golden Chaff	....	....	....	9.06	10.	9.5	2

When quantity and quality of gluten are both determined we have a much better index of loaf volume, but even then it is not possible to predict with certainty the volume of a loaf of all samples. No. 71 in the 1917 test is an example. It has about an average amount of gluten, and the gluten is of good elastic quality. A loaf of from at least 180 to 185 cubic inches could be expected from it instead of 157 cubic inches, which resulted in the baking tests.

The hard winters give an average test of 11.2 per cent gluten of very good quality. The semi-hard winters give an average of 9.9 per cent gluten rather soft elastic in quality. The soft winters show an average test of 10.3 per cent gluten soft elastic to somewhat sticky in quality.

TABLE VI.—YIELD PER ACRE IN BUSHELS

Name	1914	1915	1916	1917	Av.	No. of years	Rating Ped. No. 2=100 per cent
No. 39 Turkey Red	43.2	48.4	27.4	49.0	42.0	4	105
No. 37 Egyptian Amber	50.0	39.0	25.5	51.3	41.4	4	103
Ped. No. 408 Bacska	35.3	40.4	29.4	*35.0	35.0	4	101
Ped. No. 2 Turkey Red	40.7	37.6	30.5	51.3	40.0	4	100
No. 50 Marquis	15.2	43.0	18.4	12.9	22.4	4	56
No. 59 Nixon	... ..	54.6	30.4	51.7	45.6	3	115
No. 55 Farmer's Friend	......	56.6	27.8	48.3	44.2	3	111
Ped. No. 37 Dawson's Golden Chaff	......	......	36.3	53.2	44.7	2	108
Ped. No. 39 Dawson's Golden Chaff	......	......	31.0	49.5	40.2	2	98
No. 71 Beloglina Selection	......	......	30.5	43 0	36.7	2	89
No. 70 Beloglina Selection	......	......	26.0	37.7	31.8	2	77

* The 1917 yield of Pedigree No. 408 is taken from the records of the Ashland Branch Station. As Pedigree No. 2 yielded only 29.6 bushels per acre there, this yield instead of the yield of the Madison station is the one used to compare these two varieties in per cent rating.

Comparative Yields Per Acre

The sample in Table VI giving the highest average for the four years is No. 39 (Kansas 570). It ranks 105 per cent of Pedigree No. 2, which is two bushels per acre more in four years. Pedigree No. 2 gave the highest yield two of the four years.

Note the consistently high yields of Pedigree No. 2 and Pedigree No. 408. As before stated selections were made for both yield and milling and baking quality. No milling and baking tests were made on wheats that did not give fairly good yields. No. 37, which surpasses Pedigree No. 2 in average yield, is somewhat erratic. It gives a very low yield in 1916 and practically doubles this yield in 1914 and 1917. The 1915 yields of No. 55 and No. 59 were obtained on smaller plots than the others and are somewhat abnormal. If these yields were omitted Pedigree No. 2 would equal the higher yielder of the two.

Pedigree No. 2 and Pedigree No. 408

Pedigree No. 2, developed at the Madison station and Pedigree No. 408 developed at the Ashland branch station have been selected as the best wheats as far as tests have been carried on. Table VII gives the comparison of these two wheats for four consecutive years. The loaf volume in each case is high, Pedigree No. 2 averaging somewhat higher. The Pedigree 408 has the advantage in flour yield, water absorption, and per cent of gluten.

Comparing these wheats each year we find that one has exceeded the other at some time in each one of the items mentioned. Hence a normal fluctuation might place one ahead of the other any season, and the milling and baking qualities can therefore be considered equal.

In yields per acre they are both high, the average for the four years being practically the same.

TABLE VII.—THE PERFORMANCE OF THE TWO PURE LINE WINTER WHEATS RECOMMENDED TO MILLERS AND FARMERS FOR THEIR SUPERIOR QUALITIES—PEDIGREE NO. 2 AND PEDIGREE NO. 408

	Yield of flour per cent	Volume of loaf, cu. in.	Absorption per cent	Gluten per cent	Yield per acre
1914					
Ped. No. 2	65.3	148	61.5	10.57	40.7
Ped. No. 408	66.4	150	62.	11.13	35.3
1915					
Ped. No. 2	70.3	209	58.3	10.45	37.6
Ped. No. 408	73.8	196	56.2	10.36	40.4
1916					
Ped. No. 2	73.8	183	58.8	10.13	30.5
Ped. No. 408	73.8	181	60.9	10.56	29.4
1917					
Ped. No. 2	74.5	191	58.8	11.2	*29.6
**Ped. No. 408	73.6	182	58.8	13.8	35.0
Average					
Ped. No. 2	70.95	182.8	59.3	10.6	34.6
Ped. No. 408	71.9	177.25	59.5	11.46	35.

*Yield at Ashland Branch Station.
**Sample from Ashland Branch Station.

Pedigree No. 2 is a selection from the Turkey Red stock. It has the usual Turkey Red characters—bearded, rather short, nearly square spike, tapering somewhat at the tip. The berries are medium to large and hard, with a percentage of yellow berries which varies with the season.

Pedigree No. 408 is Bacska, C. I. 1562, obtained from Budapest, Hungary. In appearance it is very much like Turkey Red. The kernel in this particular pedigree averages slightly larger in size.

WISCONSIN PEDIGREE NO. 2 COMPARED WITH HARD SPRING WHEAT

It may be contended that all the merits of the best spring wheats cannot be set forth in a milling test made on a small experimental mill and by the ordinary baking test, but these tests furnish sufficient evidence to pass judgments on wheats for all practical purposes.

From experiments quoted earlier in this work[1] it was shown that the best spring wheats gave a test superior to the best win-

[1] Thomas, U. S. Dept. Agr. Bul. 557.

ters, but the best winters tested higher than the average of the hard springs.

In Table VIII Pedigree No. 2 gives an average for the six years superior to Marquis in every respect. Particularly in yield the Marquis is a very poor competitor, only 64 per cent of that of Pedigree No. 2.

TABLE VIII—COMPARISON OF PEDIGREE NO. 2, TURKEY RED WINTER, WHEAT, WITH WISCONSIN-GROWN MARQUIS SPRING WHEAT

	Yield of flour per cent	Volume of loaf cu. in.	Absorption per cent	Weight of loaf ounces	Yield per acre bushels
1911					
Ped. No. 2	74.5	203	52.6	17.06	21.6
Marquis	75.3	173	50.5	16.75	20.6
1912					
Ped. No. 2	74.8	196	55.3	17.25	*45.0
Marquis	73.9	201	52.3	17.31	*35.0
1914					
Ped. No. 2	65.2	148	61.5	....	40.7
Marquis	61.7	142	62.5	....	15.2
1915					
Ped. No. 2	70.3	209	58.4	17.63	37.6
Marquis	72.5	196	58.4	17.75	43.0
1916					
Ped. No. 2	73.8	183	58.8	17.81	30.5
Marquis	72.0	193	59.9	17.88	18.4
1917					
Ped. No. 2	74.5	191	58.8	17.69	51.3
Marquis	72.4	187	58.4	17.56	12.9
Average					
Ped. No. 2	72.2	188.3	57.6	17.49	37.7
Marquis	71.3	182.0	57.5	17.45	24.2

*1913 yields.

However, we find that Pedigree No. 2 does not always lead the Marquis. In flour yield Marquis exceeds Pedigree No. 2 two years out of six; in volume of loaf two years; in absorption two years (equalling it two years); in weight of loaf three years. From these facts Wisconsin Pedigree No. 2 and Wisconsin-grown Marquis can be placed on a par in milling and baking quality.

Table IX shows a five-year comparison between Pedigree No. 2 grown at the Madison station and the average northern spring wheats tested by the Howard laboratories. The five-year average is slightly in favor of the average northern springs but Pedigree No. 2 is a very close competitor.

TABLE IX.—WISCONSIN PEDIGREE NO. 2 AND AVERAGE NORTHERN SPRING WHEATS TESTED BY THE HOWARD LABORATORIES COMPARED

	Yield of flour per cent	Volume of loaf cu. in.	Absorption per cent	Weight of loaf oz.
1911				
Ped. No. 2	74.5	203	52.6	17.06
Av. northern spring	70.0	205	57.3	17.38
1912				
Ped. No. 2	74.8	196	55.3	17.25
Av. northern spring	72.0	203	55.3	17.25
1915				
Ped. No. 2	70.3	209	58.4	17.63
Av. northern spring	71.0	204	57.3	17.44
1916				
Ped. No. 2	73.8	183	58.8	17.81
Av. northern spring	72.8	197	56.8	17.44
1917				
Ped. No. 2	74.5	191	58.8	17.69
Av. northern spring	71.0	204	56.8	17.44
Average				
Ped. No. 2	73.6	196.4	56.8	17.49
Av. northern spring	71.4	202.6	56.7	17.59

Referring to Table IX we find that in a five-year test Pedigree No. 2 exceeds the average northern spring wheat four out of the five years in yield of flour, one year in volume of loaf, and three years in percentage of water absorption and weight of loaf, and equals it in these last two characters one year in the five years tested.

In the foregoing tables we find that Wisconsin Pedigree No. 2 compares very favorably with Wisconsin-grown Marquis and the average northern spring wheat in milling and baking tests, and Pedigree No. 2 and Pedigree No. 408 are much higher yielders than the best spring wheats grown at the Madison station as shown in Table IX. Therefore, at the present writing, at least, these two hard winter wheats are to be recommended above the spring wheats for southern and central Wisconsin conditions.

CUMULATIVE EFFECT OF CLIMATE UPON QUALITY

Wisconsin climate has long been considered unfavorable for the growing of good hard wheat. Millers have felt obliged to introduce new stocks from the hard wheat district every two or three years to keep up the quality.

Wheat was believed to deteriorate; i. e. to soften and lose its baking strength due to the humid climate. From conversation with millers upon this subject the writer learned that these opinions were based wholly upon observation. If these observations are correct, it puts Wisconsin in the group of semi-hard winter wheat states. This matter seemed of enough import to merit special investigation.

Several strains of Turkey wheats were introduced from Kansas in 1911. One of the best of these, Kansas No. 570 (Wisconsin No. 39), was sent to the Department of Milling Industry at the Kansas Experiment Station in 1913 and a milling and baking test was made on it and compared with the original stock grown in Kansas the same year. The results of this test are shown in Table X.

TABLE X.—MILLING TEST OF TURKEY RED WHEAT GROWN IN WISCONSIN FOR THREE YEARS COMPARED WITH THE SAME STRAIN GROWN IN KANSAS.

Variety Kansas Turkey 570, Wisconsin No. 39	Grown at Manhattan, Kansas, 1913	Grown at Madison, Wisconsin, 1913
Test weight	59 lbs.	58.75 lbs.
Straight flour	66.88 per cent.	62 8 per cent.
Feed	32.99 per cent.	34.4 per cent.
	Baking Test	
Absorption	65.00 per cent.	57.33 per cent.
Time of fermentation	236. min.	215. min.
Maximum volume of dough	2150. c. c.	2000. c. c
Oven rise	4.3 c. c.	5.2 cc.
Weight of loaf	5.34 gms.	5.07 gms.
Volume of loaf	1880. c. c.	1960. c. c.
Color of crumb	91. per cent.	95. per cent.
Texture of crumb	94. per cent.	96. per cent.

Reference to Table X shows that the Wisconsin-grown sample yielded a little less flour and was a little lower in water absorption but gave a larger loaf with a little better color and texture of crumb. The comment on the report sheet is: "This flour gave a very satisfactory loaf and compared favorably with our Kansas Turkey wheats."

COMPARISON WINTER WHEAT GROWN IN KANSAS AND WISCONSIN

In 1917, two samples of Kansas Turkey No. 570 from the 1916 and 1917 crop were received from the Kansas station and sent to the Howard laboratories to be tested. Comparisons are made with the same wheat introduced from Kansas in 1911 and grown continuously at Madison since. The results are given in Table XI.

TABLE XI.—COMPARATIVE MILLING AND BAKING TESTS OF TURKEY NO 570 (WISCONSIN NO. 39), WISCONSIN AND KANSAS GROWN

	1916		1917		2-year average	
	Kansas-grown	Wisconsin-grown	Kansas-grown	Wisconsin-grown	Kansas-grown	Wisconsin-grown
Flour yield, prct.	76.0	75.0	71.6	73.2	73.8	74.1
Color	M 1.5	M 1.5	G 2	1.5		
Quality	Cr. wh. dull	Cr. wh. L. grayish	Cr. wh. dull	Cr. wh. dull		
Loaf volume cu. in	191	154	180	185	185.5	169.5
Wt. of loaf, ounces	17.81	17.81	17.75	17.75		
Oz. water used	7.19	7.06	7.13	7.13	7.16	7.1
Color of crust	Light brown	Light brown	Light brown	Pale		
Shape	Normal	Normal	Normal	Slightly cracked on top		
Texture	Normal	Normal	Normal	Normal		
Odor	Normal	Normal	Normal	Normal		
Per cent gluten	11.6	10.31	17.3	12.4	14.5	11.35
Quality of gluten	Tough elastic	Elastic	Rather soft elastic	Elastic		

As the 1916 Kansas-grown sample was tested in 1917 this test is not entirely comparable with the 1916 Wisconsin-grown crop which was tested in 1916. The water absorption and volume of loaf is greater due to the year of storage. In flour yield the Wisconsin sample excels one year and the Kansas sample the other. The same thing is true of loaf volume. The gluten is considerably higher in the Kansas-grown sample. The other items in the test show no difference of any consequence.

In these tests (Tables X and XI) we have proof that a variety of hard wheat does not deteriorate in quality when grown in Wisconsin. This wheat has made a good record in Kansas and reference to the tables in the appendix will show that it also has made a good record in Wisconsin. After it had been grown continuously for three years in Wisconsin the milling and baking tests

indicate a very favorable comparison with the Kansas-grown sample of the same year.

The tests of 1916 and 1917, after this wheat had been grown continuously in this state for six and seven years respectively, show no appreciable differences between the Wisconsin-grown and Kansas-grown samples.

It cannot be claimed that every strain of hard winter wheat will retain its character entirely when grown in Wisconsin and until more data is collected we cannot generalize too much on

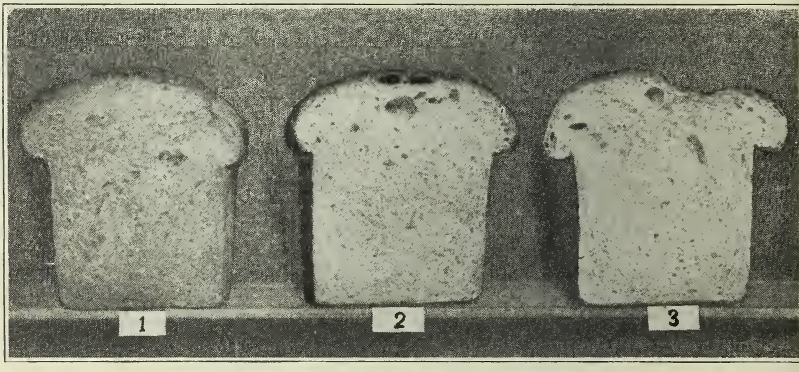

FIGURE 1.—LOAVES FROM KANSAS NO. 570—KANSAS AND WISCONSIN GROWN.

No. 1, Kansas-grown 1916; No. 2, Kansas-grown 1917; No. 3, Wisconsin-grown 1917. This type of Turkey wheat gave a very favorable test when compared with same stock grown in Kansas.

the foregoing tables. Different strains might inherit varying tendencies to soften in humid climates. However, from the foregoing data we can refute the statement that Wisconsin climate will cause every hard wheat to deteriorate in quality.

THE MILLING AND BAKING QUALITY OF THE YELLOW BERRY IN HARD WINTER WHEAT

Hard winter wheats when grown in regions having a considerable amount of moisture show a noticeable percentage of soft kernels. These soft berries are plump and light yellow in appearance, and the name yellow berry has therefore been applied to them. While they are softer than the hard berries, as a rule they are not as soft as the so-called soft wheats.

Cultural practices or handling of the crop, climatic conditions,

fertilizers and inheritance have been the main lines of investigation of the possible causes of the yellow berry. A brief review of these investigations is given.

Lyon and Keyser[1] state that "the amount of yellow berry increases as the ripeness of the grain increases and also with the length of time the cut grain is exposed to the weather." And further, that the yellow berry is inversely proportional to the protein content, "and that consequently the soil and climatic conditions previous to harvesting also affect the quality of the grain in respect to the number of yellow berries."

LeClerc and Leavitt[2] present evidence to show that the yellow berry is the result of climatic influences. To quote: "Seed grown in Kansas or South Dakota shows either no starchy grains or not more than 12 per cent at most; yet when they are transported to California and grown there the following year, the percentage of starchy grains increases to 50 and 88 per cent respectively." And further: "The California Crimean wheat of 1906 with 64 per cent of starchy grain gave a crop in Kansas with absolutely no appearance of starchy grains. It was, in fact, identical with the seeds grown continuously in Kansas. These figures again show what a tremendous factor climate is. The results further show that the white spots on grains are not necessarily hereditary nor, in fact, are any of the characteritics mentioned. They appear rather to be influenced almost altogether by climatic conditions prevailing during the growing period or even previous to the planting of the crop."

LeClerc and Yoder[3] state that "cropping thru a number of generations under widely different environments * * * does not alter permanently or make a noticeable impression upon the transmissible, physical and chemical properties of wheat."

Headden[4] states that "yellow berry can be very much lessened or entirely prevented by the application of a sufficient quantity of available nitrogen." And further he states: "Yellow berry indicates that potassium is present in excess of what is necessary to form a ratio to the available nitrogen present advantageous to the formation of a hard flinty kernel."

Inheritance has also been studied as a possible cause, Rob-

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[1] Nebraska Bul. No. 89.
[2] U. S. Dept. Agri. Bur. of Chem. Bul. 128.
[3] Jour. Agr. Res. Vol. I, No. 4.
[4] Colorado Bul. 205.

erts and Freeman[1] state that they believe that the yellow berry is heritable. However, Dr. Roberts has since stated to the writer that he was unable to verify the theory upon further investigations.

The yellow berry is very prevalent in Wisconsin and millers have considered the hard wheat grown in this state to be of very inferior quality due to this. It becomes a very practical problem to determine just how deleterious the yellow berry is in this state and to find, if possible, if there are any controllable factors influencing yellow berry production.

STUDY OF POSSIBLE CAUSES

The following studies were undertaken with the purpose of determining whether the ordinary fluctuations in climatic conditions or different cultural practices influence yellow berry production. They are incidental to the problem and are suggestive rather than definite.

Seasonal influence. Evidently the season is the greatest factor. Note the variation in percentage of yellow berry in Pedigree No. 2 for the different years as shown in Table XII. In 1914, there was 10 per cent of yellow berry in the crop. It was twice as high in 1917, three times as high in 1915, and four times as high in 1916. As this is a pure line and grown under field conditions as unvarying as possible from year to year, the variable factor evidently is the climate.

TABLE XII.—PERCENTAGE OF YELLOW BERRIES IN THE CROP OF DIFFERENT YEARS

	1912	1914	1915	1916	1917
Ped. No. 2	25	10	31	40	20
No. 39	....	23	60	....	20
No. 15	....	21	57	....	....
No. 40	....	46	71	....	....
No. 42	....	42	59	....	....
No. 41	....	58	33	....	....
No. 36	....	45	59	....	....
No. 37	....	61	82	....	....
No. 28	....	15	76	....	....

Note also that the non-pedigreed strains in 1914 show a very much smaller percentage of yellow berry in the crop than in

[1] Kansas Bul. 156.

the crop of 1915. Note also the low percentage of yellow berry in the 1917 crop of No. 39.

Inheritance. Yellow berries, flinty berries and non-selected kernels have been planted under as similar conditions as possible in different years. In no case did the pure yellow parent give a pure yellow progeny. No noticeable difference in percentage of yellow berry was evident in the different lots grown from the same parentage.

TABLE XIII.—INHERITANCE OF HARD BERRY IN A PURE LINE OF WINTER WHEAT

Plant No.	1913	1914	1815	1916	1917
		Per cent	Per cent	Per cent	Per cent
1	None	6	35	31	1 (No. 70)
9	None	8	29	43	10 (No. 71)
10	None	5	40	....	....
11	None	3	54	....	....
12	None	5	48	....	....

In 1912 selections of hard berries were made from the Beloglina stock (No. 15), to see if a superior strain of hard berries would result. Each kernel was planted separately and in 1913 only those plants were saved which had no yellow berries. The five selections thus made were planted in separate rows in the fall of 1913. The percentages of yellow berry found in the 1914, 1915, 1916 and 1917 crops are given in Table XIII. Plants 10, 11, and 12 were discarded in 1915. The selection from this lot, No. 70 and No. 71, are pure lines from plants 1 and 9 respectively. No. 71 averages considerably higher in percentage of yellow berry but in 1915, No. 70 exceeded it somewhat. The two lines are the ones referred to later in the work (Table XVII) showing a difference in milling and baking quality between two pure lines of hard winter wheat.

In 1912 counts were made on four pedigrees of Turkey Red winter wheats. Note the variation between the four pure lines from the same type of hard wheats, as shown in the following tabulation.

Pedigree No. 2	25 per cent
Pedigree No. 22	35.8 per cent
Pedigree No. 25	45.8 per cent
Pedigree No. 10	52.5 per cent

To summarize: Yellow berry will not reproduce all yellow berry. Hard berries in the same pure line will reproduce as many yellow berries in the progeny as the yellow parents will. The yellow berry character, therefore, in itself is not heritable.

We have evidence, however, to show that some pure lines of hard winter wheat will reproduce a higher percentage of yellow berries than others. Note the counts of the pedigrees of the Turkey type in 1912. Pedigree No. 2 gives less than half the percentage of yellow berries that Pedigree No. 10 gives.

The conclusion reached concerning inheritance of the yellow berry is that we need not look for a difference in reproduction of yellow berries between the yellow and hard parent in the same pure line, but that there is a very considerable difference between pure lines in their tendencies to reproduce hard berries.

Time of harvest. In 1913, 1914 and 1915 the influence of several different dates of harvest was studied on different varieties of wheat. In 1913 no yellow berries were found. In 1914 the earlier cutting dates gave a slightly higher percentage of yellow berry and in 1915 the later cutting dates gave the higher percentage of yellow berry. From these conflicting results it must be concluded that time of harvest is not the contributing factor.

Rate of seeding. In 1915 counts were made on the crops from different rates of seeding in a winter and a spring wheat. The results are conflicting and must be considered negative.

TABLE XIV.—PROTEIN DETERMINATION OF YELLOW BERRIES VS. HARD BERRIES

1911 Crop	Per cent protein in wheat	1916 Crop	Per cent protein in flour
Durum wheat, spring		Beloglina, Wis. No. 70	
Hard	14.42	Hard	10.
Yellow	12.02	Yellow	8 7
		Original	9.94
Beloglina, hard winter			
Hard	11.24		
Yellow	7.69		

PROTEIN CONTENT OF YELLOW BERRIES

It is evident from Table XIV that the yellow berry is lower in protein than the hard berry and the same statement is true of the flour made from it.

TABLE XV.—MILLING AND BAKING TESTS OF YELLOW AND HARD BERRIES IN THE 1916 CROP

	Wis. No. 70 Hard	Wis. No. 70 Yellow	Wis. No. 70 le Original samp
Flour yield	72.4	74.2	76.5
Color	Good 1 5	Good 1.5	1.5
Color quality	Cr. wh. L. dull	Cr. wh. L. dull	Cr. wh. dull
Color of crust	Light brown	Very light brown	Light brown
Vol. of loaf (cu. in.)	180	181	192
Shape of loaf	Normal	Normal	Normal
Texture of loaf	Normal	Normal	Normal
Weight of loaf (oz.)	18.13	17.81	18 06
Water used (oz.)	7.50	7.13	7.38
Gluten (per cent)	10.	8.7	10.
Gluten quality	Elastic, smooth, good	Inelastic, lumpy poor	Yellow, elastic, smooth, good

MILLING AND BAKING TESTS OF YELLOW AND HARD BERRIES

Table XV shows the results of the test made in 1916. Hand separations of yellow berries and hard berries were made from No. 70, a pure line of hard winter wheat, and with the original sample the grains were sent to the Howard Wheat and Flour Testing Laboratory of Minneapolis for milling and baking tests.

In loaf volume it will be noted that the original sample is considerably larger than the others. The hard and yellow berries show no difference of any practical importance. The yellow berry ranks with the hard winter wheats in this year's test.

Color of flour is rated the same for hard and yellow berries.

The hard berries gave the highest water absorption and weight of loaf, the original sample ranked next, and the yellow berries the lowest. In the gluten determination the yellow berries gave a lower percentage and poorer quality.

TABLE XVI.—MILLING AND BAKING TESTS OF YELLOW AND HARD BERRIES IN THE 1917 CROP

	No. 45 Hard	No. 45 Yellow	No. 45 Original sample
Flour yield	74.6	73.8	72.0
Color	1.5	1.5	1.5
Color quality	Cr. wh. dull	Wh. cr. dull	Wh. cr. dull
Color of crust	Light brown	Light brown	Light brown.
Vol. of loaf cu. in	174	160	166
Shape of loaf	Normal	Normal	Cracked across end
Texture of loaf	Normal	Normal	Normal
Weight of loaf, ounces	18.13	18.13	18.06
Water used, ounces	7.56	7.50	7.44
Gluten, per cent	11.3	9.2	10.1
Gluten, quality	Elastic	Sticky elastic	Elastic

The 1917 test shown in Table XVI was carried on in the same manner. The yellow berry class in 1916 included berries with yellow cheeks, while in 1917 only berries entirely yellow were put into this class. No. 70 had such a small percentage of yellow berries this year that it was impossible to get enough for a five-pound sample for milling test. Hence, No. 45, another pure line of hard winter wheat, was taken. This sample contained 60 per cent of yellow berry.

In volume of loaf the difference between the yellow, hard, and original samples is not very great but it is very consistent. The loaf from the yellow berry is six cubic inches smaller than that of the original sample and this is eight cubic inches smaller than the loaf from the hard berry. The original sample is almost exactly the average between the hard and the yellow. This we can expect when we note that the count of the original sample shows 60 per cent yellow berries.

In comparing the loaf volume of the yellow berries with that of the soft wheats, Pedigrees No. 37 and No. 39, we find the average of the latter only 79 per cent of the volume of the loaf from the yellow berry.

In water absorption and weight of loaf the yellow berry sample exceeds the original quite appreciably. While it is lower in water absorption than the hard berry sample, yet it is a very strong flour for it absorbed more water than any of the other hard wheats except Kharkov 208 in the 1917 test.

In amount of gluten the hard berries give the highest test and

the yellow berries the lowest. The quality of the gluten is also noticeably poorer in the latter.

A review of these two-year milling and baking tests of the yellow berry shows that it is not nearly so deleterious a factor as is generally supposed. While it averages slightly lower in loaf volume than a good sample of hard winter wheat, yet it is far superior to the soft winters. It seems to retain some of the inherited factors for good baking quality, despite the fact that it is lower in protein.

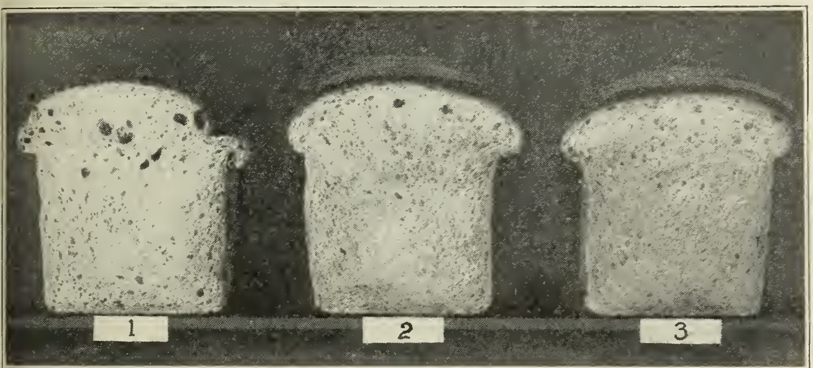

FIGURE 2.—LOAVES FROM YELLOW, HARD AND UNSORTED WHEAT OF THE SAME PEDIGREE.

No. 1, Yellow berry; No. 2, Hard berry; No. 3, Unsorted.

While the yellow berries of a hard wheat variety do not give as good a milling and baking test as the hard berries from the same sample, yet they are much superior to the soft winter wheats.

A sharp discrimination on the market is made against a sample containing a high percentage of yellow berries. For milling purposes this is justifiable, owing to the variation in texture between the yellow and hard berries, but from the baking standpoint a wide variation does not seem to exist.

VARIATION BETWEEN TWO PURE LINES FROM BELOGLINA STOCK SHOWN IN MILLING AND BAKING TESTS

A very interesting variation in baking quality between two pure lines of the same stock came to the attention of the writer in compiling the material for this publication.

In 1912, several large hard berries were selected from the

Beloglina stock (No. 15) to see if a strain could be developed which would continue to reproduce the hard character.

Two apparently superior lines were kept, No. 70 and No. 71. There is no difference in appearance between them except that No. 71 has a tendency to have a somewhat higher percentage of yellow berry. In 1916, they were tested with the others for

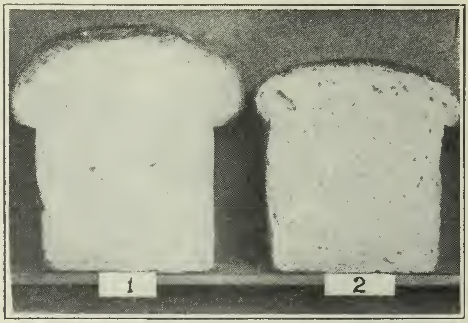

FIGURE 3.—LOAVES FROM TWO DIFFERENT PURE LINES OF TURKEY RED WHEAT.

No. 1. Wisconsin No. 70; No. 2. Wisconsin No. 71.
The loaf from No. 71 is smaller and much poorer in texture.

milling and baking quality. The variation between these two was very striking. No. 70 gave the largest loaf volume of all the hard winter wheats and No. 71 the lowest. The test was repeated in 1917 and the results are given in Table XVII.

TABLE XVII.—VARIATION BETWEEN TWO PURE LINE SELECTIONS FROM BELOGLINA STOCK SHOWN IN MILLING AND BAKING TESTS

	1916		1917		Two year average	
	No. 70	No. 71	No. 70	No. 71	No. 70	No. 71
Flour yield per cent	76.5	74.3	74.2	73.1	75.3	73.7
Color	1.5	1.5	G 1.5	M 1.5	....	....
Quality	Cr. wh. dull	Cr. wh. L. dull	Cr. wh. L. dull	Cr. wh. dull	....	....
Loaf volume cu. in.	192	137	205	157	198.5	147.
Wt. of loaf ounces	18.06	18.06	18.38	17.69	18.22	17.87
Water used ounces	7.38	7.25	6.81	6.94	7.2	7.2
Color of crust	Light brown	Light brown	Light brown	Light brown	....	....
Shape	Normal	Cracked on top	Normal	Normal	....	....
Texture	Normal	Coarse	Normal	Normal	....	....
Gluten, per cent	10.	9.94	13 2	11.8	11.6	10.87
Quality of gluten	Elastic good	Soft, poor	Very elastic	Elastic	....	....

In 1916 No. 71 was 55 cubic inches smaller in loaf volume than No. 70 and in 1917, 48 cubic inches smaller. In 1916 No. 71 gave only 71 per cent as large a loaf as No. 70 and in 1917, 76 per cent. In flour yield and amount of gluten No. 71 gives the lowest test. The quality of the gluten is noticeably inferior. In water absorption No. 71 exceeds No. 70 in 1917, yet the average for the two years is the same.

Turning to the yield per acre shown in Table VI we find No. 70 is consistently lower in yield for 1916 and 1917 than No. 71, averaging nine bushels an acre less these two years. Unfortunately, this wheat, which gives the largest loaf volume, is lowest in yields of all the winter wheats shown in Table VI. The yield is so low and the straw so weak that it cannot be recommended for practical purposes.

While a two-year test is too short for measuring differences, yet the close parallel of each year's performance cannot be attributed to accident. Heredity evidently is a very material contributor to differences both in quality and in yield. This evidence bears out the assumption made earlier that variations in results of milling and baking tests found between samples might be due, in some cases at least, to heritable qualities within the particular strains.

SUMMARY OF THE MILLING AND BAKING TESTS

The tests reported in this bulletin were carried on with the practical end in view to determine whether wheat of good quality can be grown in this state, and to select the best varieties for milling and baking quality and yield to the acre.

The spring wheats were so low in yield to the acre that with the exception of the Marquis, they were not continued long in the milling and baking tests. Two pure lines of hard winter wheat, Pedigree No. 2 and Pedigree No. 408, are recommended to millers and farmers for their excellent quality and high yield as shown in these tests.

A test in 1914 did not reveal any striking differences in milling and baking quality between pure lines of Turkey wheat grown on sandy soil, Kewaunee clay loam, and Miami silt loam. Likewise, a semi-hard winter wheat showed no appreciable difference in quality when grown upon the Kewaunee clay loam and the Miami silt loam.

In a six-year test, Wisconsin Pedigree No. 2 was fully equal to the Marquis grown at the Madison station in milling and baking quality, and considerably superior in yield.

In a five year test Wisconsin Pedigree No. 2 compares very favorably in milling and baking quality with the average of the northern spring wheats tested by the same laboratory.

Wheat does not deteriorate when grown in Wisconsin. Kansas No. 570, Wisconsin grown, compared very favorably in milling and baking quality with the Kansas-grown crop after having been grown continuously in Wisconsin for seven years.

The percentage of yellow berries in hard wheat varies with the season and with the variety. As far as tests were conducted, no evidence could be obtained showing that time of harvest or varying rates of seeding were contributory causes.

Concerning the inheritance of the yellow berry, no difference has been found between the yellow and hard berry in the same pure line in the production of yellow berry in their progeny, but there may be a wide difference between pure lines from the same stock in their tendency to produce yellow berries.

As far as baking tests show, the yellow berry cannot be considered very detrimental. In one test the loaf baked from the yellow berries equalled those from the average hard winter wheat and in the other test the loaf was comparable to the semi-hard winters.

Pure lines of hard winter wheats may be almost identical in appearance but have widely different capacity for baking quality. This heritable character was very marked in No. 70 and No. 71, the former giving a baking test equal to the best hard winters while the latter ranked with the semi-hard winters in size of loaf.

TABLE XVIII.—DESCRIPTION OF THE WHEATS ON WHICH MILLING AND BAKING TESTS WERE MADE

Hard Winter

Bearded White Chaff
- Wis. Pedigree No. 2 Turkey Red
- Wis. Pedigree No. 6 Turkey Red
- Wis. Pedigree No. 10 Turkey Red
- Wis. Pedigree No. 11 Turkey Red
- Wis. Pedigree No. 14 Turkey Red
- Wis. Pedigree No. 21 Turkey Red
- Wis. Pedigree No. 22 Turkey Red
- Wis. Pedigree No. 25 Turkey Red
- Wis. Pedigree No. 29 Turkey Red
- Wis. Pedigree No. 32 Turkey Red
- Wis. Pedigree No. 33 Turkey Red
- Wis. Pedigree No. 408 Bacska
- No. 15 Beloglina
- No. 38 Kharkov. Kansas No. 382
- No. 39 Turkey Red. Kansas No 570
- No. 40 Crimean. Kansas No. 762
- No. 42 Bearded Fife, Kansas No. 366
- No. 70 Selection from Beloglina
- No. 71 Selection from Beloglina
- No. 45 Turkey Red
- No. 108 Kharkov
- No. 208 Kharkov

Beardless White Chaff
- No. 41 Ghirka, Kansas No. 385

Bearded Red Chaff
- No. 103 Red Rock

Semi-Hard Winter

Bearded Red Chaff
- No. 36 Tasmanian Red

Bearded White Chaff
- No. 37 Egyptian Amber
- Wis. Pedigree No. 40 Egyptian Amber
- No. 55 Farmer's Friend—Purdue Reg. 320
- No. 59 Nixon

Beardless White Chaff
- No. 208 Padi

Soft Winter

Beardless Red Chaff
- Wisconsin Pedigree No. 13
- Wisconsin Pedigree No. 17
- Wisconsin Pedigree No. 20
- Wisconsin Pedigree No. 37 Dawson's Golden Chaff
- Wisconsin Pedigree No. 39 Dawson's Golden Chaff

Beardless White Chaff
- Wis. Pedigree No. 40

Bearded Red Chaff
- No. 609 Selection from Kharkov

Soft Spring

Beardless Bronze Chaff
- No. 23 John Brown

Hard Spring

Bearded White Chaff
- No. 7 Preston
- No. 33 Blue Ribbon

Beardless White Chaff
- No. 27 Fife
- Wisconsin Pedigree No. 34 Fife
- No. 29 Marquis
- No. 50 Marquis
- No. 30 Blue Stem
- No. 31 Blue Stem
- Wis. Pedigree No. 35 Blue Stem

THE HOWARD SYSTEM OF MARKINGS

In order to make the following tables clear, a brief statement of the Howard system of markings is necessary. Five pounds of wheat are used in the milling and baking tests; 12 ounces of flour are used in baking loaves. Color is maked numerically, 1 being the best, 1.5 next lower, and so forth. Letters used in this connection are M. minimum, G. good, F. fair, Cr. creamy, Wh. white. Where the abbreviation is underlined, the quality is particularly prominent.

TABLE XIX.—MILLING AND BAKING TESTS, 1911 CROP

Name	Per cent yield of flour	Flour Color	Flour Quality	Vol. of loaf cu. in.	Wt. of loaf oz.	Water used oz.	Protein analysis of wheat N× 5.7
Ped. No. 11	74.8	F 1	Wh. cr ...	199	17.19	6.44	11.68
Ped. No. 21	76.8	F 1	Cr. wh....	198	17.06	6.25	10.61
Ped. No. 22	75.3	G 1.5	White, little dull.	204	17.06	6.38	10.69
Ped. No. 14	75.5	G 1.5	Wh. cr. little dull	203	17.00	6.19	12.16
Ped. No. 17	75.8	G 1.5	Cr. wh little dull.	183	17.13	6.38	11.73
Ped. No. 32	71.0	1.5	Cr.wh.dull	207	17.06	6.31	11.97
Ped. No. 33	75.3	1.5	Cr.wh.dull	201	17.25	6.5	11.11
Ped. No. 6	73.0	1.5	Cr.wh.dull	196	17.25	6.56	11.79
Ped. No. 2	74.5	P 1.5	Cr.wh.gr'y	203	17.06	6.31	12.36
Ped. No. 25	74.8	1.5	Cr. wh. little dull.	188	17.25	6.44	10.98
Ped. No. 10	76.0	P 1.5	Cr.wh.gr'y	181	17.31	6.75	11.99
Ped. No. 13	73.5	1.5	Cr. wh. little dull.	183	17.19	6.38	10.98
Ped. No. 29	75.3	1.5	Cr. wh. little gray	173	16.75	6.06	10.94
Ped. No. 20	77.8	1.5	Cr. wh. little dull.	178	16.91	6.06	11.57
Ped. No. 15	76.5	1.5	little dull.	183	17.38	6.75	11.18
Ped. No. 23	75.5	1.5	Cr. wh. little dull.	194	17.19	6.38	11.84

TABLE XX.—MILLING AND BAKING TESTS, 1912 CROP

Name	FLOUR			LOAF				
	Yield per cent.	Color	Quality	Vol. cu. in.	Weight oz.	Water used oz.	Protein in wheat	Gluten per cent
Ped. No. 2	74.8	G 1.5	Cr. wh.L. dull	196	17.25	6.63	12.08	10.83
Ped. No. 21	74.7	F 1.	Cr. wh.L. dull	201	17.13	6.31	11.17	10.
Ped. No. 6	74.8	F 1.	Cr. wh.L. dull	195	17.31	6.63	11.04	9.58
Ped. No. 22	74.9	F 1.	Cr. wh.L. dull	186	17.06	6.31	10.98	10.21
Ped. No. 11	73 4	F 1.	Wh. cr.	175	17,25	6.5	10.45	9.79
No. 15	76.1	F 1.	Cr. wh.	·190	17.13	6.38	10.52	10.63
No. 33	74.6	1.5	Cr. wh. dull..	203	17.19	6.38	13.52	12.5
No. 31	73.8	1.5	Cr. wh.L. dull	212	17.31	6.63	14.16	....
No. 30	73.2	P 1.5	Cr. wh. dull..	197	17.75	7.0	16.10	....
No. 29	73.9	1.5	Cr. wh. dull..	201	17.31	6.63	13.62	....
No. 23	74.3	G 1.5	Wh. cr. little grayish	198	17.25	6.5	15.11	....

TABLE XXI.—MILLING AND BAKING TESTS, 1913 CROP

Name	Gluten			Chemical Analysis of Wheats					
	Wet	Dry	Qualtity	Water	Protein	Fat	Fiber	N. free extract	Ash
Ped. No. 2...	38.4	12.8	Elastic.......	9.19	15.82	1.71	2.95	68.5	1.83
Ped. No. 6...	33.6	11.2	Stiff elastic..	9.32	14.72	1.71	2.92	69.4	1.90
Ped. No 11 .	34.8	11.6	Elastic.......	9.42	14.47	1.53	2.65	70.14	1.79
Ped. No. 21..	36.2	12.0	Elastic.......	9.47	14.82	1.69	3.5	69.13	1.84
Ped. No 22.,	35.6	11.8	Elastic.......	9.63	13.88	1.72	2.93	70.15	1.69
No. 39.......	37.2	12.4	Elastic.......	9.77	14.91	2.32	2.36	68.94	1.7
No. 15.......	35.2	11.6	Elastic.......	9.63	14.66	1.6	2.89	69.36	1.86
No. 36.......	38.0	12.8	Soft elastic..	9.73	15.47	1.65	2.56	68.70	1.89
No. 37.......	30.4	10.0	Soft elastic..	9.45	14.91	1.96	2.49	69.43	1.76
No. 38.......	35.2	11.6	Elastic.......	10.19	14.25	1.57	2.51	69.82	1.65
No. 40.......	33.6	11.2	Elastic.......	9.77	14.07	1.49	2.33	70.57	1.77
No. 41.......	36.8	12.2	Elastic.......	9.97	14.28	1.59	2.53	69.79	1.84
No. 42.......	38.0	12.8	Elastic.......	9.73	16.07	1.58	2.52	68.38	1.72
No. 7.......	40.0	13.2	Soft elastic..	9.53	16.10	1.96	2.81	67.5	2.1
No. 27.......	38.8	12.8	Soft elastic..	9.59	15.22	2.40	2.96	67.68	2.15
No. 29.......	41.6	14.0	Elastic.......	9.56	17.13	2.21	2.99	66.02	2.09
No. 30.......	39.6	13.2	Elastic.......	9.69	16.63	1.95	2.77	66.9	2.06
No. 31.......	40.0	13.2	Elastic.......	9.38	16.25	1.91	2.99	67.52	1.95
No. 33.......	46.0	15.2	Soft elastic..	9.31	16.54	1.80	2.56	67.69	2.16
No. 50.......	41.2	13.6	Elastic.......	9.89	16.22	2.13	2.50	67.36	1.90

TABLE XXII.—MILLING AND BAKING TESTS, 1914 CROP

Name	Flour				Loaf				
	Per cent yield	Color	Absorption	Ash	Vol. cu. in.	Water used oz.	Quality	Wt. of dough oz.	Gluten per cent
No. 39	67.1	99	62.5	.36	138	7.03	Rich crust—good quality loaf	20.	11.20
Ped. No. 408	66.4	99	62.	.40	150	6.97	Very rich crust—excellent quality loaf	19.9	11.13
Padi No. 208	65.	98	61.	.36	151	6.85	Very creamy—rich crust—good quality loaf	19.7	9.37
No. 41	67.7	98	62.	.44	120	6.97	Crust little pale—fair quality loaf	19.8	9.75
Kharkov No. 609	66.2	96	58.	.38	107	6.49	Poor quality loaf—dough soft—pale crust	19.3	9.06
No. 36	68.8	96	61.5	.42	128	6.91	Rich crust—little dull—creamy—good quality loaf	19.7	10.07
Kharkov No. 208	66.4	97	62.	.40	121	6.97	Rich crust—fair quality loaf	20.	9.56
Kharkov No. 108	68.5	97	61.	.34	119	6.85	Little pale—fair quality loaf	19.7	9.75
No. 50	61.7	100	62.5	.54	142	7.03	Very good quality loaf—very rich crust	19.9	12.46
No. 33	65.2	97	61.5	.38	135	6.91	Rich crust—little dull—fair quality loaf	19.9	12.14
Standard patent	....	100	64.	....	150	7.21	....	20.2	11.5
Ped. No. 2 (Miami silt loam)	65.2	99	61.5	.50	148	6.85	Little creamy—rich crust—very good quality loaf	....	10.57
Ped. No. 2 (Kewaunee clay loam)	63.6	99	62.5	.42	150	7.03	Little creamy—rich crust—very good quality loaf	....	11.51
Ped. No. 21 (Sandy soil)	61.1	99	62.	.32	150	6.97	Little creamy—rich crust—excellent quality loaf	....	10.57
Ped. No. 21 (Kewaunee clay loam)	62.7	98	62.	.34	145	6.97	Very creamy—rich crust—good quality loaf	....	9.88
No. 37 (Kewaunee clay loam)	62.5	96	58.	.44	137	6.49	Dough soft—pale crust—poor quality loaf	....	8.55
No. 37 (Miami silt loam)	64.5	97	61.	.36	139	6.85	Soft dough—very pale crust—fair quality loaf	....	9.69
No. 15	65.2	99	61.	.46	148	6.85	Little creamy—rich crust—very good quality loaf	....	10.07
No. 38	62.3	97	60	.26	148	6.73	Pale crust—fair quality loaf	....	11.8
No. 42	65.1	98	60.5	.34	148	6.79	Very creamy—rich crust—very good quality loaf	....	10.51
No. 40	67.2	99	61.5	.32	146	7.03	Little creamy—rich crust—very good quality loaf	....	10.46

TABLE XXIII—MILLING AND BAKING TESTS, 1915 CROP

Name	Flour			Loaf						Gluten	
	Yield Per cent	Color	Quality	Vol. cu. in.	Weight ounzes	Water used ounzes	Color of crust	Shape	Texture	Per cent	Quality
Ped. No. 2..	70.3	1.5	Cr. wh. L. dull...	209	17.63	7.00	Very light brown	Normal....	Normal....	10.45	Elastic
No. 39	72.6	1.5	Wh. cr. L. dull...	203	17.5	6.94	Very light brown	Normal	Normal....	10.60	Rather soft elastic
No. 36	70.6	G 1.5	Wh. cr. L. dull...	205	17.25	6.69	Very light brown	Normal	Normal....	10.61	Rather softelastic
Ped. No. 408	73.8	1.5	Cr. wh. L. dull...	196	17.31	6.75	Very light brown	Normal	Normal....	10.36	Elastic
No. 41.......	72.7	1.5	Wh. cr. L. dull...	185	17.69	7.00	Very light brown	Normal..	Normal.,...	9 63	Elastic
Padi No. 208	72	G 1.5	Yellowish white...	187	17.06	6.31	Very light brown	Normal	Normal ...	8.64	Soft elastic
No. 38	73.4	G 1.5	Cr. wh. L. dull...	160	17.75	7.00	Pale................	Normal	Large hole	9.39	Elastic
No. 55.......	73.9	1.5	Wh. cr. L. dull...	148	17.63	6.81	Very light brown	Cracked on top	Normal....	9.78	Soft sticky elastic
No. 37.......	76.8	1.5	Wh. cr, L. dull...	160	17.19	6.44	Very light brown	Normal.........	Normal....	10.38	Soft elastic
No. 59,......	73.2	G 1.5	Wh. cr. L. dull...	136	17,31	6.69	Very light brown	Cracked on top	Large hole	10.17	Soft elastic
No. 40.......	74.4	G 1.5	Cr. wh............	160	17,38	6.69	Very light brown	Normal	Normal.....	9.84	Elastic
No. 42.......	74.3	1.5	Yellowish white... L dull...........	191	17.44	6.81	Very light brown	Normal	Normal.....	10.09	Elastic
No. 50.......	72.5	G 2	Wh. cr. dull.......	196	17.75	7.00	Very light brown	Normal	Normal.....	13.70	Very elastic

TABLE XXIV.—MILLING AND BAKING TESTS, 1916 CROP

Name	Flour			Loaf						
	Yield per cent	Color	Quality	Vol. cu. in.	Wt. oz.	Water used, oz.	Color of crust	Shape	Texture	Gluten per cent
No. 70 H. B.	72.4	Good, 1.5	Cr. wh., little dull	180	18.13	7.5	Light brown	Normal	Normal	10
No. 70 Y. B.	74.2	Good, 1.5	Cr. wh., little dull	181	17.81	7.13	V. light brown	Normal	Normal	8.7
No. 70 Original	76.5	1.5	Cr. wh., dull	192	18.06	7.38	Light brown	Normal	Normal	10
No. 71	74.3	1.5	Cr. wh., L. dull	137	18.06	7.25	Light brown	Cracked on top	Coarse	9.94
No. 39	75.0	M., 1.5	Cr. wh., L. grayish	154	17.81	7.06	Light brown	Normal	Normal	10.31
Ped. No. 38	72.	Good, 1.5	Wh. cr., L. dull	151	17.75	6.94	V. light brown	Normal	Normal	8.11
Ped. No. 2	73.8	1.5	Wh. cr.. dull	183	17.81	7.06	Light brown	Normal	Normal	10.13
Ped. No. 408	73.8	1.5	Cr. wh., dull	181	18.13	7.31	Light brown	Normal	Normal	10.56
Ped. No. 39	74.3	1.5	Cr. wh., L. dull	113	17.38	6.50	Light brown	Normal	Coarse	9.06
Ped. No. 37	72.8	1.5	Cr. wh., L. dull	110	17.38	6.50	Light brown	Normal	Normal	11.25
No. 37	70.5	1.5	Wh. cr., dull	138	17.31	6.69	V. light brown	Cracked on top	Normal	8.06
No. 59	71.2	M., 1.5	White, L. grayish	138	17.38	6.69	Light brown	Normal	Coarse	8.44
No. 55	71.5	M., 1.5	White, L. grayish	128	17.38	6.75	V. light brown	Cracked on top	Normal	8.19
Ped. 34	73.5	M., 1.5	Wh. cr., L. grayish	128	17.50	6.75	Light brown	Normal	Coarse	11.94
Ped. 35	70.3	M., 1.5	Cr. wh., dull	168	17.38	6.63	Light brown	Normal	Normal	12.03
No. 50	72.0	M., 2.	Cream, dull	193	17.88	7.19	Light brown	Normal	Normal	12.25
Av. No. 1 N. Spr	72.8	Good, 1.5	Cr. wh., little dull	197	17.44	6.81	Light brown	Normal	Normal	....

FIGURE 4.—LOAVES OF THE 1917 CROP

No. 1. Av. Northern Spring Wheat
No. 2. Pedigree No. 2, Turkey Red
No. 3. Pedigree No. 408, Bacska
No. 4. Wisconsin No. 50, Marquis
No. 5. Wisconsin No. 103, Red Rock
No. 6. Wisconsin No. 55, Farmer's Friend
No. 7. Pedigree No. 40, Egyptian Amber
No. 8. Wisconsin No. 59, Nixon
No. 9. Pedigree No. 208, Kharkov
No. 10. Pedigree No. 39, Dawson's Golden Chaff
No. 11. Pedigree No. 37, Dawson's Golden Chaff

Compare the best hard winters, Nos. 2 and 3, with sample No. 1, Av. Northern Spring Patent, and with Nos. 10 and 11, soft winters.

TABLE XXV.—MILLING AND BAKING TESTS, 1917 CROP

Name	Flour			Loaf						Gluten	
	Yield per cent	Color	Quality	Vol. cu. in.	Wt. oz.	Water used oz.	Color of crust	Shape	Texture	Per cent.	Quality
Ped. No. 2	74.5	M 1	Cr. wh. L. dull	191	17.69	7.06	Pale	Normal	Normal	11.2	Tough, elastic
No. 39	73.2	1.5	Cr. wh. dull	185	17 75	7.13	Pale	Slightly cracked on top.	Normal	12.4	Elastic
Turkey 570. Kans 1917	71.6	G. 2	Cr. wh. dull	180	17.75	7.13	Light brown.	Normal	Normal	17.3	Rather soft, elastic
Turkey 570. Kans. 1916	76.	M 1.5	Cr. wh. dull	191	17.81	7.19	Light brown.	Normal	Normal	11.6	Tough, elastic
No. 70	74.2	G 1.5	Cr. wh. L. dull	205	17.38	6.81	Light brown.	Normal	Normal	13.2	Very elastic
No. 71	73.1	M 1.5	Cr. wh. dull	157	17.69	6.94	Light brown.	Normal	Normal	11.8	Elastic
Kharkov No. 208	73.9	M 1.5	Wh. cr. dull	145	18.19	7.44	Light brown.	Cracked on top	Coarse	13.6	Rather soft elastic
Ped. No. 408	73.6	M 1.5	Cr. wh. dull	182	17.75	7.06	Light brown,	Normal	Normal	13.8	Elastic
No. 103	72.8	2	Wh. cr. L. grayish	175	17.13	6.56	Light brown.	Cracked on top	Normal	15.	Elastic, sticky
Ped. No. 37	75.2	1.5	Cr. wh. dull	125	16.88	6.25	Light brown.	Cracked on top	Coarse	11.2	Soft, elastic
Ped. No. 39.	75.	G 1.5	Cr. wh. L. dull	130	16.94	6.25	Light brown.	Cracked on top	Fair	10.	Soft, elastic, sticky
Ped. No. 40	73.9	1.5	Wh. cr. dull	159	17.13	6.44	Light brown.	Slightly cracked	Normal	11.6	Rather soft, elastic
No. 59	71.8	1.5	Wh. cr. L. dull	150	17.38	6.75	Light brown.	Normal	Normal	11.2	Rather soft, elastic
No. 55	72.	G 1.5	Wh. cr. L. dull	160	17.19	6.63	Light brown.	Normal	Normal	11.8	Rather soft, elastic
No. 50	72.4	1.5	Wh. cr. dull	187	17.56	7.	Light brown.	Normal	Normal	12.	Tough, elastic
No. 45	72.0	1.5	Wh. cr. dull	166	18.06	7.44	Light brown.	Cracked across end	Normal	10.1	Elastic
No. 45 H. B.	74.6	1.5	Cr. wh dull	174	18.13	7.56	Light brown.	Normal	Normal	11.3	Elastic
No. 45 Y. B.	73.8	1.5	Wh. cr. dull	160	18.13	7.50	Light brown.	Normal	Normal	9.2	Sticky, elastic
Av. normal Spr. straight fresh ground	....	G 2	Cr. dull	204	17.44	6.81	Light brown.	Normal	Normal	11 50	Elastic

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Farm Tenancy

An Analysis of the Occupancy of 500 Farms

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MADISON

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An Analysis of the Occupancy of 500 Farms

Introduction

The National Committee on Standardization of Research in Country Life, which was appointed at the annual meeting of the American Sociological Society in 1917, proposed that some re-

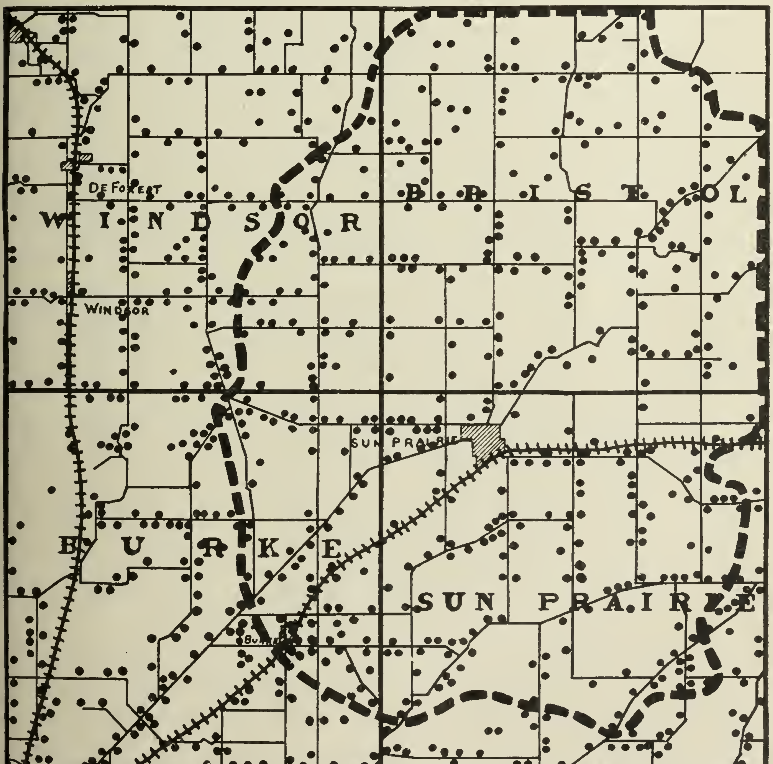

FIG. 1.—MAP OF THE SUN PRAIRIE COMMUNITY

That portion of the map enclosed within the broad dotted line contains the 500 farms visited. Each dot represents a farmstead. The whole map is made up of four townships. The Sun Prairie Community includes a part of each of these townships. Highways are indicated by unbroken lines. Railways are represented by crossed lines.

sponsible agency in every state make a field study of farm tenancy in certain communities of the state. It was recommended by the committee that the social aspects of tenancy, and especially

the shifting of farm tenants, form the body of the investigation. In accord with this plan of cooperative national research, the Department of Agricultural Economics of the College of Agriculture selected a Wisconsin community and made an analysis of its farm tenancy.

During the month of September, 1918, Miss Emily F. Hoag, assistant in agricultural econonmics at the University of Wisconsin, made a farmstead to farmstead visit with a horse and buggy to 500 farm homes in Dane county, Wisconsin, obtaining a history of the occupancy of each farm during the ten-year period, 1909–18. The selection of this particular group of farms was made with the intent of including all the farms belonging in one business community,—and no other farms. Fortunately, there was available a recent map of the county showing all the farm homes grouped together, which regularly trade at any one business center.

Sun Prairie, a vigorous village of some 1200 inhabitants, is the business and institutional center of the particular community chosen to be studied. All told, a population of about 3500 persons is involved in this community; and village churches, library, newspaper, banks and high school serve both farmers and townsmen. From the social point of view, it will be important to bear in mind that the land-holding relations on these 500 farms are interwoven in one community fabric. The map shows the relative location of the farms studied in the trade area of Sun Prairie.

The method of field work was simple. Previous to the visit to the farms, an announcement was made in the local paper explaining the purpose of the visit to each farm. This prepared the way and made an approach to each home easy.

A map showing the location of every farm home on its own highway was indispensable. These farm homes were numbered serially up to 500 and each farm was given its number on the field sheets.

The sample field sheet shows exactly how the information was recorded. The general question put to each family was, "Who has occupied this farm in each of the last ten years?" Then, naturally, conversation would develop as to the facts of ownership, tenancy, relationship of tenants, etc. In cases where the present occupant did not know all the facts, neighbors were usually found who did know. A few odds and ends of unfin-

ished data were referred to bankers, merchants, retired farmers, and the encyclopedic old settler, with success.

A recent rural directory of the county was of considerable assistance in hunting down the present status of persons who had moved out of the Sun Prairie community. This directory was also the source of facts on sizes of farms, and on present residence and status of retired farmers.

SHIFTING OF FARM TENANTS

Community											
Farm No.	Name of Farm	1918	1917	1916	1915	1914	1913	1912	1911	1910	1909
209	A. Rand	B	A. Rand BX⊗	A	A	A	A	A	A	A	F. Hard A
			see No. 17								
210	B. Garr	A	B. Garr AXO	Vacant Woodlot owned by T. Brown							
			see 24 36								
211	C. E. Burns	A	A	A	A	C. E. Burns AX	△ 4## B. Harper	□ 3## P. Baker	△ 2#	2x# R. Noll	△ 1# O. Rick
							see No. 187			O.N. 213 see 160	see 372 42
212	L. Alber	B	B	B	B	B	L. Alber BX	△ 1#	1#	1x# J. Wells	△ A L. Alber
								O.N.			
213	D. Ray 1	D. Ray Jr. A⊗	D. Ray Jr. 5=X	R. Burns 4#	D. Ray B	△ 3## H. Burns	□ 2## L. Tate	△ 1x# R. Noll	A	A	U. Hope A
		son	son	neighbor see 207	No Shift see No. 214	see 386		O.N. see 160 211			
214	D. Ray 2	A	A	A	A	A	A	A	A	A	D. Ray A
215	Jones Place	P. Ritter 3##	△ 2 =	R. Jones 2X=	△ 1 =	1=	1=	1=	1=	1=	C. Jones 1=
		(Tobacco)	O.N.	son see 490							son see 38
216	A. Harper	A	A	A	A	A	A	A. Harper AX⊗	1=	1=	K. Clap 1=
											neighbor see 127

A.B.C. etc. represents owner on farm
1, 2, 3 " " tenant " "
x = Shift from same community
# = " " another "
O = Formerly owner of another farm
O.N. = Present (1918) "

□ = Shift to another community
△ = " " same "
= = Related to family of owner
= Not related to family of owner
θ = Tenant was just previously an owner
⊗ = Owner " " " a tenant

FIG. 2.—SAMPLE SHEET OF THE FIELD RECORD

This record sheet gives the history of eight farms, as set down at the time of the visits to the farms.

The tables relating to "retired farmers" were an after-thought growing out of the field study. A list of the retired farmers living in Sun Prairie was furnished by the local business men's association as a possible source of information. The list, together with the constant reiteration of the fact that Mr. So-and-so is a retired farmer, suggested to the investigator that the retired farmer was closely connected with the problem of tenancy and merited consideration in the study. Thereupon, a supplementary study was made of the retired farmer. As soon as the problem of tenancy was actually connected with the problem of

the retired farmer, it became apparent that the gradual "advance" of youths into farming corresponded with the slow "retreat" of veterans from farming.

The main statistical facts of the study are presented in table form, without, however, any attempt at this time to interpret them. That analyses similar to this in many parts of Wisconsin and other states will enable students of agricultural tenantry to think more clearly on the subject, goes without saying.

It is hoped that rural social investigators in every state will begin a close examination of farm tenancy from the viewpoint of the human relations involved in each farmstead situation.

PART I.—OCCUPANCY OF FARMS

TABLE I.—FARMS OCCUPIED BY OWNERS AND TENANTS

	1918	1917	1916	1915	1914	1913	1912	1911	1910	1909
Total number of farms...	493	491	485	479	476	475	472	466	465	463
Number of farms occupied by owners..........	347	344	336	343	352	349	354	362	356	368
Number of farms occupied by tenants.........	146	147	149	136	124	126	118	104	109	95
Owner per cent...	71—	71—	70—	72—	74—	74—	75—	78—	77—	80—
Tenant per cent	29+	29+	30+	28+	26+	26+	25+	22+	23+	20+

Farms not leased during the ten years.......	246
Farms leased during ten-year period	42
Farms sometimes leased, sometimes not leased..........................	212

While the total number of different farms in the Sun Prairie community during the ten-year period is 500, it is evident that, due to the occasional division of farms and the shifting of land from one farm to another, the number of farms will tend to vary from year to year. A few tenants occupy more than one farm at the same time.

It is a matter of some interest that 246 farms were constantly occupied by their owners; that 42 farms were constantly leased and may be classed as "tenant farms"; and that 212 farms were in a state of oscillation between owner occupants and tenant occupants.

Table II.—Farms Occupied by Tenants Related and Unrelated to the Owners

	1918	1917	1916	1915	1914	1913	1912	1911	1910	1909	Total
Number of farms occupied by tenants related to owners............	70	70	72	61	56	50	51	46	45	36	125
Number of farms occupied by tenants unrelated to owners...........	76	77	77	75	68	76	67	58	64	59	154
Per cent of related tenants...........	47+	47+	48+	44+	45+	39+	43+	44+	40+	37+	......
Per cent of unrelated tenants.....	53—	53—	52—	56—	55—	61—	57—	56—	60—	63—	... ..

In estimating the advantages and disadvantages of the American system of tenancy, it has been urged of late that an analysis of all tenants in a community will show a certain rather constant proportion of the tenants to be related to the landlord. The above table, it is worth mentioning, confirms the contention that much tenancy is a *modus vivendi* of a near relative, and a procedure quite satisfactory to both parties, if not always in reality a step toward ownership wherein inheritance plays a distinct rôle.

The degree of relationship in this table is almost invariably that of son or son-in-law. One case each of a nephew, a brother, a father-in-law and a cousin is included.

Nine farms were occupied continuously during the ten-year period by tenants related to the owners; 33 farms, by tenants unrelated to the owners. The total number of farms occupied by tenants related to the owners turns out to be 125; by tenants unrelated, 154; by tenants both related and unrelated, 25.

PART II. PURCHASE OF FARMS

TABLE III.—STATUS OF FARM PURCHASERS

Purchasers Not Formerly Owners of Farms						Formerly owners	Unknown	Total
Tenants			Non-tenants					
Sons buying home farm after renting it	Unrelated tenants buying farm after renting it	Unrelated tenant buying other farm than one rented	Sons buying home farm	Sons buying other than home farm	Coming from other occupations			
32	4	59	16	31	7	65	4	218

The total number of transfers of title to farms in the Sun Prairie community during the ten-year period, was made up of 218 instances where the purchaser actually lived on the farm purchased, and a few cases only (less than a dozen) where the purchaser simply made an investment and did not live on the farm.

It will appeal to many as a rather curious fact that so few of the class of unrelated tenants purchase, when buying farms, the same farm which they have rented. On the other hand it is quite as one would expect that sons should purchase the home farm after renting it.

The practice of a son's renting the home farm is evidently general; but it is offset by the more general practice of sons working at home for wages until able to buy a farm, whereupon, often with the father's help, they purchase either the home farm or a neighboring farm.

It is worth noticing as a piece of rural sagacity in the climb up the "agricultural ladder," that 79 sons who purchased farms kept close to the father as adviser or landlord, and presumably received the father's material backing when it came to purchase.

Two tenant farms owned by the same person have come to be known as "owner-producing farms": one of them, the landlord remaining the same, produced from its tenants four owners in the ten-year periods; the other, two owners. since 1913.

TABLE IV.—PRESENT STATUS OF FARM TENANTS.

Tenants	Owners outside community	Owners inside community	Retired	Other occupations	Unknown	Total
143	16	89	7	14	58	327

TABLE V.—SIZES OF FARMS RENTED AND PURCHASED

	1918	1917	1916	1915	1914	1913	1912	1911	1910	1909
1	O-120	O-120	O-120	O-120	T-105	T-105	T-105	T-105	T-105	....
2	O-77	O-77	O-77	O-77	O-77	O-77	T-160	T-160	T-160	T-160
3	O-160	O-160	O-160	O-160	T-180	T-180	T-180	T-180	T-180	T-160
4	O-140	O-140	O-140	T-118	T-160	....	....	....	....	....
5	O-17½	O-17½	O-17½	O-17½	O-17½	T-118	T-118	....	....	....
6	O-120	O-120	O-120	O-120	O-120	T-80	T-80	T-80	T-80	T-80
7	O-93	O-93	T-80	....	....	....	....	....	....	....
8	O-80	O-80	O-80	O-80	O-80	O-80	O-80	T-97½	T-97½	T-97½
9	O-100	O-100	O-100	O-100	O-100	O-100	O-100	O-100	O-100	T-155
10	O-80	O-80	O-80	T-30 (Tob)	T-30 (Tob)	T-80	....	....	....	....
11	O-77	T-20 (Tob)	T-20 (T ob)	T-185	T-185	....	....	....	....	....
12	O-81½	T-80	T-80	T-80	T-80	T-80	T-80	T-18½ (Tob)	....	....
13	O-85	O-85	O-85	O-85	O-130	T-80	T-80	T-80	T-80	T-80
	O-100	O-100	T-100	T-100	T-100	....	....	....	....	....
14 15	O-38½ T-120	T-160	T-160	T-160	T-160	T-160	T-160	T-160	T-160	T-160
16	O-80	O-80	O-80	O-80	O-80	T-100	....	....	....	....
17	O-80	O-80	O-80	O-80	O-80	O-80	O-80	T-120	T-120	T-203
18	O-80	O-80	T-40	T-40	T-40	T-40	T-40	T-40	T-40	T-40
19	O-80	O-80	O-80	O-80	T-60	(No Record)		T-60	T-60	T-60
20	O-40	O-40	O-40	O-40	O-40	O-40	O-40	O-40	T-120	T-107
21	O-96	O-96	O-96	O-96	O-96	O-96	O-96	O-96	T-200	T-200
22	O-80	O-80	O-80	O-80	O-80	O-80	O-80	O-80	O-80	T-105
23	O-20	O-20	O-20	(At home on father's farm)			T-60	T-60	T-180	....
24	O-120	O-120	O-120	O-120	O-120	T-80	T-80	T-80	T-80	T-80
25	O-72	O-72	O-72	T-100	....	....	....	....	....	....
26	O-40	O-40	T-80	T-80	T-80	T-80	T-80	....	....	....

(Tob)=Tobacco farm.
O-120=Owns 120 acres
T-105=Leases 105 acres

The total number of different tenants who leased any one of the 500 farms during the ten-year period is 327,—not counting, however, the "neighbor tenants," who, as a matter of fact, own adjoining farms in addition to leasing.

Of the 105 tenants who climbed the "agricultural ladder" during the ten-year period and became owners, 16 purchased farms outside the community of Sun Prairie (not included in Table III) and 89 purchased farms within the community. Seven persons who were tenants outside but purchased farms inside the community are not counted in the group of tenants who climbed the "agricultural ladder."

The "retired" tenants are those who have ceased farming due to advanced age. Those tenants who entered "other occupa-

tions'' are young men who left the farm for the town. Six of these, however, enlisted as soldiers. The tenants of ''unknown'' status include those who have moved out of the county, as well as those who have died.

It has been pointed out by economists that American tenancy affords an opportunity for the farmer to discover the size of farm best adapted to his capacity before actually making an investment in land. With this thought in mind it will prove of some interest to look over Table V of 26 young tenant-farmers, unrelated to the owners of their tenant farms, who, during the ten-year period, became owners of farms. In each case the farm purchased is a totally different farm from the one previously leased.

PART III.—RETREAT OF FARM OWNERS

TABLE VI.—GENERAL STATUS OF RETREATING FARMERS

Ownership	Still owning some farm	78	Total
	Not owning any farm now	46	124
Residence	Living on some farm	1	
	Living in town	46	
	Moved out of county	7	124
Employment	Still actively farming	20	
	Overseeing or helping	41	
	Tenant or hired man	7	
	With other employment	23	
	With no employment	33	124
Status of those living in town	Managing farm	4	
	With other employment	14	
	With no employment	28	46
Men		101	
Women		23	124

TABLE VII.—GENERAL STATUS OF THOSE STILL OWNING SOME FARM

Residence	Living on own farm	61	Total
	Living in town	16	
	Moved out of county	1	78
Employment	Still actively farming	20	
	Overseeing or helping	37	
	With other employment	7	
	With no employment	14	78
Status of those living on own farm	Working own farm	20	
	Living with son-tenant	23	
	Living with relative-tenant	2	
	Living with unrelated-tenant	5	
	Living with neighbor-tenant	11	61

Table VIII.—General Status of Those Not Now Owning a Farm.

Residence	Living on some farm	10	Total
	Living in town	30	
	Moved out of county	6	46
Employment	Overseeing or helping	4	
	With other employment	16	
	Tenant or hired man	7	
	With no employment	19	46
Status of those living on farm	Living with son-owner	3	
	Tenants	6	
	Hired man	1	10

TABLE IX.—GENERAL STATUS OF RETREATING WOMEN FARMERS

Ownership	Still owning original farm	18	Total
	Sold original farm	5	23
Residence	Living on farm	17	
	Living in town	6	23
	Still owning; living on farm	16	
	Still owning; living in town	2	
	Sold farm; living on farm	1	
	Sold farm; living in town	4	23
Status of those living on farms	Still owning; living with son-tenant	8	
	Still owning; living with unrelated tenant	2	
	Still owning; living with neighbor-tenant	6	
	Sold farm; living with son-owner	1	17

The number of farm-owners on the 500 farms who started their retreat (retirement) from farming during the ten-year period was 124. Old age came to some farmers unannounced and suddenly, and retirement was forced at once. In other cases the sag in strength was gradual and retreat took place inch by inch. The fighting spirit seems to cling to the land and to work as long as possible.

This constant social phenomenon of retreating old age seems to have a fixed relationship to the advance of youth upon the land and to the "climbing of the agricultural ladder." The foregoing tables are presented in the hope that analyses of other constant social phenomena, whose relation to tenancy is as yet unnoticed, may follow and may throw as much light on this important problem as the familiar instance of the retired farmer.

The table of women owners shows that, when farm land comes under the control of women, instead of leaving the country they

tend to stick to the farm in spite of many handicaps, keeping the family together, leasing farm to neighbors, until a son is old enough to assume the responsibility of management.

TABLE X.—OCCUPANCY OF FARMS OF RETREATING OWNERS

	1918	1917	1916	1915	1914	1913	1912	1911	1910	1909
Held by tenants;										
By son managing	38	34	31	29	27	24	18	14	12	3
By relative managing	3	3	3	2	1	1	1	0	0	0
By unrelated tenant managing	10	11	13	13	12	10	9	7	5	3
By neighbor managing	9	10	5	6	4	4	4	2	3	2
Held by purchasers:										
By son managing	14	12	12	9	6	5	5	2	1	0
By relative managing	0	1	0	0	0	1	1	1	1	0
By unrelated person managing, formerly tenant somewhere	13	15	13	10	12	12	9	4	2	1
By unrelated person managing, formerly owner somewhere	14	11	11	11	9	10	9	3	0	0
By unrelated person managing, from other employment	1	0	0	0	0	0	0	0	0	0
By unrelated person managing, formerly neighbor	1	0	0	0	0	0	0	0	0	0
By unrelated person managing, young man on first farm	9	9	4	5	5	1	0	0	0	0
Held by original owners:										
By owner returned	4	3	2	2	1	1	0	0	0	0
By owner	0	8	24	32	41	46	58	79	87	96

Evidently in any considerable community there will be found, in any one year, farmers just starting their retreat from farming, farmers well along in their retreat, and farmers whose retreat may be said to be completed. In the community of Sun Prairie are many farmers still living whose retreat was either complete or in process prior to 1909. These farmers do not appear, and are not considered, in the present study. Only those farmers are entered in the tables who started their retreat some time during the ten-year period. All of these are considered, whether they finish their retreat within the period or not.

The foregoing table tells the story, year by year, of how many of the original farms have been let slip out of the working grasp of the farm-owners under consideration into the hands of tenants or purchasers.

In 1909, only 8 farm-owners began their retreat. They started the retreat by letting their farms to tenants. In 1910, (including those farmers that began to retreat in 1909 whose farms are still held by tenants in 1910) 18 farm-owners are in full retreat by letting their farms to tenants, while 3 farm-owners

began their retreat by selling their original farms. In other words, each year has a record of the number of farms rented or sold, as the first step in retreat, combined with the number of farms still held by tenants and purchasers from the preceding years of the period. A particular farm may pass obviously from the "held by tenants" class to the "held by purchasers" class, or *vice versa.*

TABLE XI.—OCCUPANCY OF DIVIDED FARMS OF RETREATING OWNERS

	1918	1917	1916	1915	1914	1913	1912	1911	1910	1909
Held by										
1. Son tenant, original owner............	3	2	1	1	1	0	0	1	1	3
2. Three unrelated tenants...............	1	1	1	0	0	0	0	0	0	0
3. Two son tenants.......................	0	0	1	1	1	1	1	1	1	
4. Unrelated tenant, neighbor purchaser	1	0	0	0	0	0	0	0	0	
5. Unrelated tenant, son purchaser.....	0	0	0	1	0	0	0	0	0	
6. Son purchaser, son tenant.............	1	1	1	0	0	0	0	0	0	
7. Two son purchasers....................	1	1	0	0	0	0	0	0	0	0
8. Son purchaser, original owner........	0	0	0	0	0	1	1	1	0	0
9. Neighbor purchaser, original owner..	0	1	1	1	1	1	1	0	0	0
10. Unrelated purchaser, son purchaser.	0	0	0	0	1	0	0	0	0	0
11. Neighbor purchaser, son purchaser ..	1	1	1	0	0	0	0	0	0	0

Dividing the farm, the owner retaining a part, while quite evidently a form of retreat, is not a method which suggests itself readily to a retreating farmer, even when a son is the part-tenant or part-owner. The difficulties of such a situation are easily seen. However, it is interesting to notice in the few instances of this manner of retreat, that a son or a neighbor now and then fulfills the happy conditions.

In 1909, four sons held a part of the farms as tenants; but in 1910 they do not appear in the table. As a matter of fact, they changed in 1910 to the class of tenants holding the whole farm, while the fathers took one more step in the retreat. It is plain that the status of any particular divided farm may change in like manner to some form of tenancy or purchase of the whole farm.

Divided farms must not be confused with joint tenant farms or jointly owned farms. When a farm is divided it becomes two or more farms.

TABLE XII.—FARMS OTHER THAN ORIGINAL HELD BY RETREATING FARMERS

	1918	1917	1916	1915	1914	1913	1912	1911	1910	1909
Held as owner:										
Second farm, selling original	11	12	10	10	5	5	6	3	0	0
Second farm, leasing original	4	5	6	5	4	2	2	2	1	0
Third farm, leasing other two	1	1	0	0	0	0	0	0	0	0
Held as tenant:										
Tenant on another farm	6	7	7	7	7	5	4	2	1	0

A distinct step in the retreat of some farmers is the purchase of a second farm, either much smaller than the original farm or else lying close to town, often even within the limits of town; most frequently the second or third farm combines both factors, smallness and nearness to town.

In cases where the second farm is in the open country and of good size, it is usually found that the retreating farmer has leased or sold the original farm to an older son while having in mind to provide a farm for a younger son, who later either leases or buys the second farm. A third farm for a third son is not unknown.

When a retreating farmer sells out and becomes a tenant on another farm of ordinary size in the open country, we find the cause usually in some form of break-up of the family, usually death of the wife. This circumstance is the beginning of a series of steps in retreat—as tenant, boarding with the owner's family, or as tobacco-farmer living in town, or in other employment.

TABLE XIII.—RESIDENCE OF RETREATING FARMERS

	1918	1917	1916	1915	1914	1913	1912	1911	1910	1909
Living on original farm	49	55	65	67	72	77	84	96	102	105
Living in town	46	38	32	30	30	27	18	11	8	3
Moved out of county	7	6	5	4	4	3	3	1	1	0
Living on second farm	15	17	16	15	9	7	8	5	1	0
Living on third farm	1	1	0	0	0	0	0	0	0	0
Living on another farm	6	7	6	7	7	4	4	2	1	0

That the town has truthfully been considered the goal of the retreating farmer, this study will more or less justify. The special light, however, thrown upon the "retired farmer" shows him as moving off his farm by degrees: giving over a part of his house to the newcomer; moving into a smaller house on the original farm; going to live with a son on another farm; moving on to a smaller farm near town; settling in a house in town surrounded by a large garden.

The tenant system appears to be a cog fitting into the notched edges of the veteran farmer's retreat.

TABLE XIV.—EMPLOYMENT OF RETREATING FARMERS

	1918	1917	1916	1915	1914	1913	1912	1911	1910	1909
Still owning original farm:										
Working original farm	4	12	26	34	42	44	58	79	87	96
Working part of original farm	3	3	2	2	2	2	2	2	1	3
Overseeing or helping on original farm	35	34	31	29	27	27	23	17	14	8
With other employment	5	7	7	6	5	5	3	2	2	0
With no employment	13	8	7	7	8	5	3	3	3	0
Working second farm	3	4	5	4	3	1	1	0	0	0
Working third farm	1	1	0	0	0	0	0	0	0	0
Overseeing or helping on second farm	1	1	1	1	1	1	1	2	1	0
Having sold original farm:										
Overseeing or helping on original farm	4	4	3	2	2	2	2	2	1	0
With other employment	17	12	11	10	11	10	8	1	1	1
Tenant on another farm	6	7	7	7	7	5	4	2	1	0
Hired man on another farm	1	1	0	0	0	0	0	0	0	0
With no employment	20	17	14	11	9	8	6	2	2	0
Tenant on original farm	0	1	0	0	0	0	0	0	0	0
Working second farm	10	11	9	8	3	4	6	3	0	0
Overseeing or helping on second farm	1	1	1	2	2	1	0	0	0	0
Totals	124	124	124	123	122	118	117	115	113	108

That the retiring farmer gives up the habit of work only upon compulsion of circumstances is evident from the foregoing table of his employment, especially from that part of the table dealing with no employment.

It cannot fail to interest the person who thinks upon the tenant problem in terms of human relationships to find that the veteran farmer, though sagging in his physical strength, is able to impart, in the opportune role of overseer or helper, a portion of the wisdom gained by his years of farm experience to young men in the natural role of tenants.

PART IV. SHIFTING OF TENANTS

TABLE XV.—NUMBER OF SHIFTS

	1918	1917	1916	1915	1914	1913	1912	1911	1910	1909	Total
Of all tenants	30	51	59	56	47	48	47	39	38	14	429
Of all tenants shifting within the community	20	31	32	38	29	24	29	20	24	6	253
Of all tenants shifting to and from other communities	10	20	27	18	18	24	18	19	14	8	176
Of tenants related to owner	7	9	18	6	5	6	7	7	7	3	75
Of tenants unrelated to owner	23	42	41	50	42	42	40	32	31	11	354

Every change in the occupancy of a farm home involves a shifting of each of two families,—one moving off the farm and another moving on. To estimate the degree of influence a shifting tenantry has upon the stability of a community it will be necessary to count the coming of a family to a farm as one shift and the going of a family as distinctly another shift. For it is plain that, from the social point of view, pulling up the roots of a family established in the neighborhood affects every social relationship in the neighborhood in a peculiar manner; and the planting in of a new family is a new influence requiring new social adjustments at every point.

A few explanations must be made as to how the foregoing table of shifts is made up. A farm may change occupants several times in ten years and yet no family will be found to have shifted on or off the farm. This circumstance is illustrated best in the case of a son, brought up on the farm, who becomes a tenant on the home farm. It also is illustrated in the case of a neighbor who becomes a tenant on an adjoining or nearby farm. These cases are not counted as shifts in the table.

When a family moves on to a farm as tenant and while occupying this farm rents a second farm nearby, its coming is reckoned as a shift only on the first farm.

When, however, a son, after once leaving his father's farm, moving on to another farm or going to reside elsewhere, returns as a tenant on the home farm, his coming back is reckoned as a shift.

If a son while living on, but not renting, his father's homestead becomes a tenant on a nearby farm, whether the second farm is

owned by his father or by some other person, no shift is reckoned as taking place. However, if the son moves on to the second farm, a shift is counted.

Whenever a son-in-law comes to lease his father-in-law's farm, a shift occurs and is counted.

In the case of a joint tenancy on one farm by two families, one shift for each family is counted for each move.

The comparative stability of related tenants suggests that there may be methods as yet untried which would render the unrelated tenant a more stable part of the community.

TABLE XVI.—NUMBER OF FARMS ON WHICH SHIFTS OCCURRED

	1918	1917	1916	1915	1914	1913	1912	1911	1910	1909	Total
Number of different farms involved in the shifts:											
Of all tenants	30	42	43	42	40	39	38	31	32	14	142
Of tenants shifting within the community	20	28	24	31	27	22	27	17	20	6	120
Of tenants shifting to and from other communities	10	19	23	18	17	19	15	17	14	8	89
Of related tenants	7	9	13	6	5	6	7	6	7	3	51
Of unrelated tenants	23	33	30	36	35	33	31	25	25	11	119

Neighbors generally know the farms on which shifting of tenants occurs with frequency and regularity. If a community is going to exercise social control of its tenant shifting, so as to cut down the cases of preventable shifting, it will carefully examine the conditions of tenancy on the farms where shifting is chronic.

It will be recalled from Table I that 254 farms of the 500 were at some time occupied by tenants. The present table discloses the significant fact that only 142 of these farms had any shifts of tenants during the ten-year period. On the other hand, it turns out that 17 farms have had one or more shifts in each of five or more years of the ten-year period, and may well be considered as "chronic-shifting farms."

Table II shows that the total number of "related farms" is 125. This present table shows that only 51 of these farms have had shifts, while 119 of the 154 "unrelated farms" have had shifts.

TABLE XVII.—NUMBER OF SHIFTING TENANTS

	1918	1917	1916	1915	1914	1913	1912	1911	1910	1909	Total
All tenants	30	41	46	42	40	39	38	31	32	14	231
Tenants shifting within the community	20	27	27	31	27	22	27	17	20	6	146
Tenants shifting to and from other communities	10	19	23	18	17	19	15	17	14	8	138
Both within and without	....	....	....	....	....	....	....	....	....	....	53
Related tenants	7	9	15	6	5	6	7	6	7	3	59
Unrelated tenants	23	32	31	36	35	33	31	25	25	11	179
Both related and unrelated	....	....	....	....	....	....	....	....	....	....	7

The total number of different tenants shifting is 231 out of the 327 tenants. Against the 5 "chronic shifters" may be set these 96 tenants who do not shift during the ten-year period. A tenant is considered a "chronic shifter" if he makes one shift or more in each of five or more years of the ten-year period. The chronic shifter may never, obviously, be a tenant on a "chronic-shifting farm."

TABLE XVIII.—INDEX NUMBERS OF TENANT SHIFTING

	1918	1917	1916	1915	1914	1913	1912	1911	1910	190
Number of farms	493	491	480	479	476	475	472	466	465	463
Number of possible shifts	493	982	970	958	952	950	944	932	930	463
Index number of shifting tenancy										
Index of all tenant shifts	30/493 .0588	51/982 .0519	59/970 .0608	56/958 .0584	47/952 .0493	48/950 .0505	47/944 .0519	39/932 .0418	38/930 .0408	14 4 .030
Index of intracommunity shifts	20/493 .0385	31/982 .0315	32/970 .0329	38/958 .0396	29/952 .0304	24/950 .0252	29/944 .0307	20/932 .0215	24/930 .0258	6 .012
Index of intercommunity shifts	10/493 .0203	20/982 .0203	27/970 .0277	18/958 .0187	18/952 .0189	24/950 .0252	18/944 .0190	19/932 .0203	14/930 .0150	8 .017

The number of possible shifts is reckoned as follows: In the years 1909 and 1918 only one shift to each farm is considered possible. In 1909, a family is assumed to be occupying each farm without a shift to the farm, so that only a shift off the farm is possible. In 1918 a family is assumed to be remaining on each farm without a shift off, so that only a shift on to the farm is possible. For each of the other years two shifts to each farm are considered possible,—viz., one off and one on.

The index number of tenant shifting for any particular year is obtained by dividing the number of actual shifts by the number of shifts possible in that year. For the purpose of comparing tenancy in different communities situated in various parts of the United States, the system of index numbers will be found useful.

Research Bulletin 45 August, 1919

The Common Cabbage Worm in Wisconsin

(Pontia rapae Linn.)

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AGRICULTURAL EXPERIMENT STATION
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AGRICULTURAL EXPERIMENT STATION
OF THE UNIVERSITY OF WISCONSIN

MADISON

The Common Cabbage Worm in Wisconsin

(Pontia rapae Linn.)

The growing of cabbage is one of Wisconsin's important agricultural industries and the cabbage root maggot and imported cabbage worm are the most serious insect enemies of the cabbage crop.

During the last three years, the imported cabbage worm has caused serious losses in Wisconsin and many questions have been received concerning the danger of spraying cabbage plants. The fact that many of the canners refuse to buy or use sprayed cabbages constitutes one of the chief difficulties of the grower. If he does not spray the worms destroy the plants, and if he does spray he runs the risk of not being able to sell his crop. The present investigation was undertaken to try to help both the grower and the canner by determining the actual facts in the case.

That the cabbage worm can be easily controlled and also that cabbage can be sprayed without danger to the consumer is a fact more or less well established. The general public is not acquainted with these facts, however, and by the use of suitable illustrations it can be shown that it is profitable to spray cabbages and that they can be sprayed without danger to the consumer.

Many miscellaneous observations have been recorded on this insect and the various stages have been described, but no one seems to have presented a complete study of its life cycle and general economic importance.

History and Distribution

The actual date and method of introduction of this insect into North America are unknown but the first definitely recog-

nized specimens were taken at Quebec, Canada, in 1860, by William Couper. J. G. Bolles, 1864, concludes that the insect must have been present in the vicinity of Quebec as early as 1856 or 1857. Scudder* in his discussion of its introduction draws the conclusion that it could not have been in this country previous to 1860 or, at the very earliest, in 1859; otherwise someone would have noticed it because of "the rapidity with which a single pair may propagate without hindrance from parasites." He was no doubt justified in this conclusion because published records show that it spread over large areas of territory in the short period of two or three years. Beginning in 1860 it had by 1863 spread for many miles in all directions around the city of Quebec, and in 1864 it was found 90 miles south of Quebec at Murray Bay. In 1865 specimens were collected in Vermont and New Hampshire and in 1869 near New York.

Working westward and southward it had spread by 1872 well into New York and the province of Ontario in Canada. It appeared in North Carolina as early as 1870 and in Alabama in 1873, but these later importations were probably brought about by carrying in individuals other than those of the main migration. By 1871, the different colonies started in the northeastern United States had mingled, and in 1872 Scudder records them as having extended in a continuous line as far south as Virginia and as far west as Ontario, Canada, and the Allegheny Mountains in Pennsylvania. In the spring of 1873 a few specimens were found at Cleveland, Ohio, and at Chicago in 1875.

P. R. Hoy found the first Wisconsin specimens at Racine in 1879. In 1881 specimens were collected in Texas and Nebraska and records show that it was more or less continuous from Alabama to Wisconsin, the species having been previously recorded as well established in Iowa and Missouri in 1878. A correspondent wrote Scudder that it had reached North Dakota in 1883 and Montana in 1884, but he believes it is possible that in the latter case the correspondent was mistaken in the identification of the specimens at hand. It was first recorded from Colo-

* For a detailed account on the introduction and spread of *Pieris rapae* in North America from 1860–1886 see article by Samuel Scudder in the Memoirs of Boston Society of Natural History, pp. 53–69.

rado in 1886 by David Bruce, who collected a number of specimens near Denver between August and October.

W. G. Wright, 1889, gives the following notes on *Pieris rapae* from California. "In May, 1883, I captured in this place one male of that species (identified by George D. Hulst), since when I have never seen another specimen, although collecting butterflies every year and usually extensively. That sample I have yet in my cabinet." It was next reported from southern California by Mr. Wright in 1896.

Hillman reported seeing it in Nevada in 1897, and Fletcher reported it from Vancouver Island, British Columbia, in 1900. It is now a common insect about the cabbage fields of western Washington and Oregon.

FOOD PLANTS

Cabbage and cauliflower are the main food plants although a number of larvae have been found feeding on wild mustard, radish and horseradish. Other writers report their feeding on cabbage, cauliflower, radish, rutabaga, horseradish, mustard, mignonette, nasturtium, tropaeolum, sea rocket (Cakile americana?), water cress, pepper grass, shepherd's purse, sweet alyssum, spider plant, stinkweed, and lettuce.

NATURE AND EXTENT OF INJURY

The general nature of the damage caused by the cabbage worm is not hard to determine, but few growers realize the extent of the damage. In average seasons there is considerable loss, although the crop may be sufficiently large to make the actual decrease in the crop of little economic value. However, in seasons when climatic conditions are unfavorable to the growth of cabbage, the losses occasioned by insect damage are enormous.

Under Wisconsin conditions early varieties of cabbage are not damaged to any great extent as the crop is harvested before the worms become at all abundant. On the other hand, late varieties are set out about the time when the eggs of the second generation are being deposited in greatest numbers.

The eggs are, for the most part, deposited on the outside or under-surface of the leaves and the young larvae which feed there have a chance to do considerable damage before they are noticed. In many cases they destroy the leaf surface as fast as it appears and prevent the formation of the head. This often happens in the case of cauliflower plants, which seem to have a tendency to throw all the growth into the formation of leaves when under adverse conditions. Occasionally the injury is sufficient to check the growth of the plants almost completely. This is shown in a comparison in figure 1. One plant was not

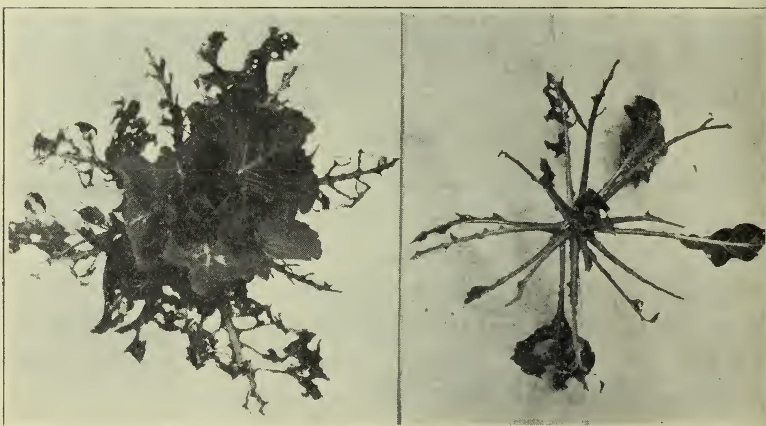

FIG. 1—INJURED PLANTS CAN BE SAVED BY SPRAYING

These pictures were taken 22 days after the plant on the right was sprayed once. The sprayed plant free of worms was able to start and develop a head.

sprayed at all; the other plant was sprayed once 22 days before the pictures were taken.

With the mature heads the damage is caused by the larvae eating the leaves and cutting tunnels into the heads.

As a result of this the heads are soft and unfilled and the filthy green castings which the worms leave behind them make the heads unsightly and undesirable for use.

A fact which seems not to have been noted before is the great damage caused by the eating away of the terminal portions of the leaves. Each leaf is so developed that its point overlaps and adheres to the leaf opposite forming what we

have designated as a friction cap. Referring to figure 2, one may notice that the head is formed from the inside and that the earliest leaves form a shell into which the later growth is forced in a hard compact mass. If for any reason the development of this shell or casing is prevented, then the leaves grow straight outward and up and the head is immature and soft, as shown. The cabbage worms seem to prefer the outer edges of the leaves and in eating away those parts destroy the fold or friction cap which forms the shell.

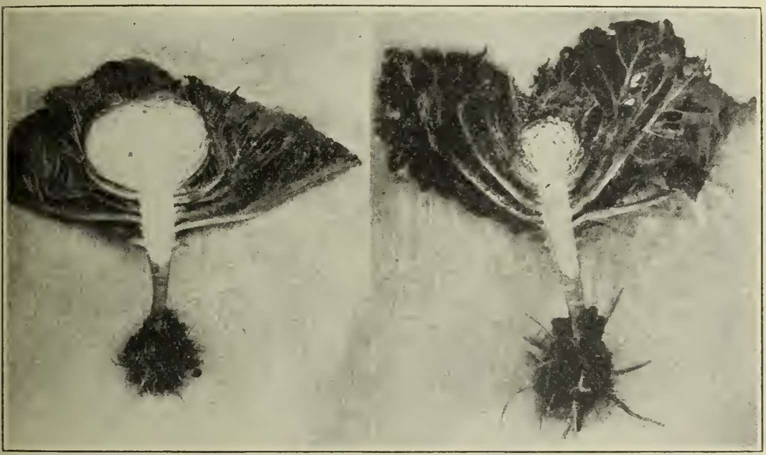

FIG. 2.—DESTRUCTION OF FRICTION CAP PREVENTS FORMATION OF THE HEAD

When the tips of the leaves are eaten away the friction cap is destroyed and a compact solid head cannot be formed.

Frequently the mature heads are not attacked until late in August or September (figure 3) at which time the worms eat away portions of the heads and tunnel for short distances directly into them. In other cases they will eat through one or more leaves and work downward to the leaf base, where they continue to feed and leave their castings. In practically every case heads thus attacked are unfit for market.

In making observations during the last of August and the first of September, 1917, a large field of cabbage was counted in which there were 3,211 plants. The cabbage worm had damaged 917 heads to such an extent that they were totally unmarketable. Others were more or less damaged to an extent

of 35 per cent by the cabbage worm. In many home gardens in and about Madison not a single head was fit for table use.

EXPLANATION OF LIFE HISTORY CHARTS FOR 1916

In all, 105 larvae were started but a good many of these died and their numbers are omitted. In obtaining the data, butterflies were reared, or netted and caged, and the date of

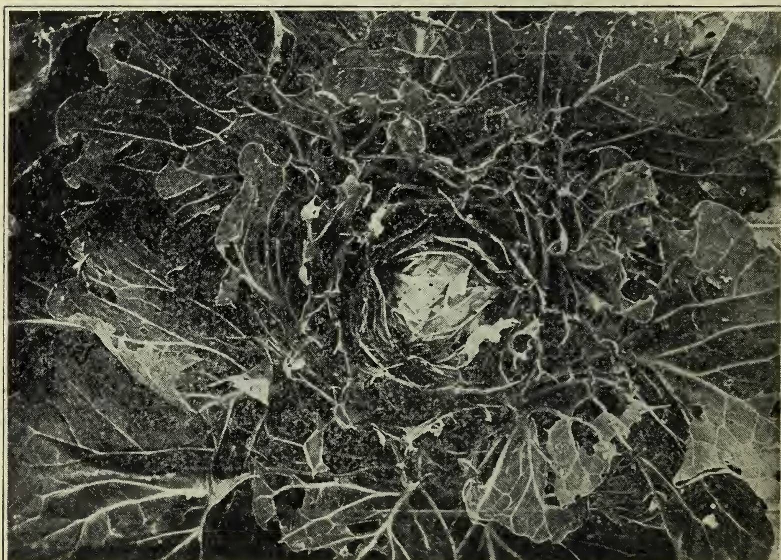

FIG. 3.—ONE APPLICATION OF SPRAY WOULD HAVE MADE THIS HEAD MARKETABLE

Many heads not attacked early in the season are destroyed after the head is formed by worms tunnelling through the outer leaves

egg deposition noted. In all cases, daily observations were made and cotton was placed about the base of the plants to catch cast skins if any dropped down.

FIRST GENERATION

The larvae included under numbers 1 to 13 represent the beginning of the first generation. The first butterfly emerged on April 16, but they did not appear in numbers until after May 1. The first eggs were secured in the field on May 6, the

date on which the rearing cages were started. A second series was started May 9 and a third series on May 31.

While the eggs in the last series were laid 25 days after those of the first series, the butterflies of the last series began to emerge only 10 days later than those of the first. The average period of development for the first generation was 54.7 days. By June 25 all butterflies had disappeared from the field but by July 1 they were again emerging and on July 10 were quite abundant. The butterflies in the insectary began to emerge at practically the same time. July 8 the first butterfly from the May 31 series emerged, and the last one of this series emerged on July 16, from an egg deposited May 30.

SECOND GENERATION

The exact date of deposition is not known for eggs 46 to 54 but the dates on the remainder are definite and the incubation period may be safely applied to the others. The average number of days required for the transformation of this brood was 26 days, or less than half the period required for the first generation.

A second series was also started for this generation on July 27, the average period required for maturity of the individuals being 29 days. Adults of this generation began to emerge in the insectary by July 31 but they did not appear abundant in the field until a few days later. At this time we had difficulty in the breeding cages and were unable to get eggs except by following butterflies in the field.

THIRD GENERATION

August 14 the third generation was started but only six of the eggs were carried through to the chrysalis stage. The average period for development in this generation from egg to pupa was 25½ days. None of the adults emerged in the fall of 1916 and for some reason the chrysalids died during the following winter.

TABLE I.—DURATION OF LIFE STAGES OF THE COMMON CABBAGE WORM—FIRST GENERATION: 1916

No.	LARVA						PUPA	ADULT
	Egg	Hatched	Molt 1	Molt 2	Molt 3	Molt 4	Molt 5	Molt 6
1	May 6	May 11	May 20	May 26	May 28	June 1	June 12	June 27
2	May 6	May 11	May 20	May 24	May 29	June 4	June 15	June 30
3	May 6	May 11	May 23	May 26	June 1	....	....	....
4	May 6	May 12	May 23	May 27	June 1	June 11	June 20	July 2
5	May 6	May 13	May 23	May 26	May 30	June 4	June 14	June 30
6	May 6	May 12	May 24	May 28	June 1	June 9	June 18	June 30
7	May 6	May 12	May 24	May 26	May 31	June 8	June 18	July 1
8	May 6	May 13	May 24	May 27	June 2	June 11	June 14	July 2
9	May 6	May 12	May 24	June 1	June 4	June 10	June 17	July 1
10	May ?	May 30	June 4	June 12	June 14	June 21	June 30	*
11	May 9	May 18	May 26	May 31	June 4	June 10	June 21	July 1
12	May 9	May 18	May 24	May 27	June 1	June 11	June 18	July 2
13	May 9	May 18	May 25	May 28	June 2	June 11	June 17	July 2
14	May 31	June 6	June 13	June 19	June 27	July 1	July 2	July 16
15	May 30	June 5	June 14	Iune 20	June 25	June 30	July 1	July 15
16	May 31	June 6	June 14	June 17	June 22	June 27	July 2	July 10
17	May 31	June 5	June 13	June 20	June 22	June 27	July 2	July 10
18	May 31	June 6	June 14	June 20	June 25	June 27	July 2	July 12
19	May 31	June 6	June 14	June 20	June 25	June 27	July 2	July 10
20	May 31	June 6	June 13	June 17	June 20	June 25	June 50	July 8
21	May 31	June 6	June 14	June 20	June 25	June 27	July 2	July 10
22	May 31	June 6	June 14	June 20	June 25	June 27	July 2	July 10
23	May 31	June 6	June 14	June 20	June 25	June 27	July 6	July 15
24	May 31	June 6	June 13	June 17	June 20	June 27	June 30	July 10
25	May 31	June 6	June 12	June 16	June 20	June 25	June 30	July 8
26	May 31	June 6	June 11	June 16	June 20	June 22	June 30	July 9
27	May 31	June 6	June 11	June 15	June 20	June 25	June 30	July 8
28	May 31	June 6	June 11	June 15	June 20	June 25	June 30	July 10
29	May 31	June 6	June 11	June 15	June 20	June 25	June 30	July 10
30	May 31	June 6	June 13	June 18	June 21	June 27	July 2	July 10
31	May 31	June 6	June 11	June 15	June 20	June 25	July 2	July 10
32	May 31	June 6	June 11	June 17	June 20	June 25	July 2	July 10
33	May 31	June 6	June 11	June 17	June 20	June 25	June 30	July 10

* Parasitized by A. glomeratus. Parasites emerged July 6.

TABLE II.—DURATION OF LIFE STAGES OF THE COMMON CABBAGE WORM—SECOND GENERATION: 1916

No.	Larva						Pupa	Adult
	Egg	Hatched	Molt 1	Molt 2	Molt 3	Molt 4	Molt 5	Molt 6
34	July 5	July 13	July 16	July 18	July 21	July 24	July 28	Aug. 3
35	July 5	July 10	July 14	July 16	July 19	July 22	July 31	Aug. 3
36	July 5	July 11	July 13	July 15	July 18	July 21	July 25	Aug. 3
37	July 5	July 11	July 15	July 18	July 21	July 24	July 26	Aug. 4
38	July 5	July 11	July 13	July 16	July 18	July 21	July 25	July 31
39	July 5	July 12	July 19	July 21	July 24	July 26	July 31	Aug. 7
40	July 12	July 16	July 18	July 21	July 24	July 25	July 28	Aug. 6
41	July 12	July 16	July 18	July 19	July 21	July 24	July 26	Aug. 3
42	July 12	July 15	July 18	July 19	July 21	July 24	July 28	Aug. 4
43	July 12	July 16	July 18	July 21	July 22	July 24	July 26	Aug. 3
44	July 12	July 15	July 18	July 19	July 21	July 25	July 27	Aug. 3
45	July 12	July 12	July 14	July 16	July 18	July 19	July 24	July 30
46	July 7*	July 13	July 16	July 18	July 21	July 22	July 26	Aug. 2
47	July 12	July 13	July 16	July 18	July 21	July 24	July 26	Aug. 3
48	July 12*	July 15	July 17	July 18	July 19	July 21	July 25	July 31
49	July 12*	July 15	July 18	July 19	July 21	July 24	July 26	Aug. 3
50	July 12*	July 15	July 18	July 19	July 22	July 24	July 27	Aug. 3
51	July 12*	July 15	July 17	July 18	July 19	July 21	July 24	July 31
52	July 12*	July 15	July 18	July 19	July 21	July 22	July 26	Aug. 3
53	July 12*	July 15	July 16	July 18	July 19	July 21	July 25	July 31
54	July 12*	July 15	July 18	July 19	July 21	July 22	July 25	Aug. 1
55	July 14	July 18	July 21	July 24	July 25	July 27	July 31	Aug. 6
56	July 14	July 18	July 21	July 22	July 24	July 27	July 31	Aug. 6
57	July 27	July 30	Aug. 3	Aug. 5	Aug. 8	Aug. 10	Aug. 18	Aug. 26
58	July 27	July 31	Aug. 4	Aug. 6	Aug. 8	Aug. 15	Aug. 18	Aug. 26
59	July 27	July 31	Aug. 4	Aug. 6	Aug. 8	Aug. 14	Aug. 17	Aug. 24
60	July 27	July 31	Aug. 4	Aug. 6	Aug. 8	Aug. 9	....	....
61	July 27	July 31	Aug. 4	Aug. 6	Aug. 8	Aug. 15	Aug. 18	Aug. 26
62	July 27	July 31	Aug. 4	Aug. 8	Aug. 9	Aug. 15	Aug. 18	Aug. 26
63	July 27	July 31	Aug. 4	Aug. 6	Aug. 8	Aug. 9	Aug. 14	Aug. 23
64	July 27	July 31	Aug. 4	Aug. 8	Aug. 14	Aug. 16	Aug. 19	Aug. 29

*About July 10 to July 12.

TABLE III.—DURATION OF LIFE STAGES OF THE COMMON CABBAGE WORM—THIRD GENERATION: 1916

No.	Larva						Pupa	Adult
	Egg	Hatched	Molt 1	Molt 2	Molt 3	Molt 4	Molt 5	Molt 6
65	Aug. 14	Aug. 19	Aug. 23	Aug. 24	Aug. 28	*		
66	Aug. 14	Aug. 17	Aug. 19	Aug. 23	Aug. 26	Aug. 29	Sept. 8	
67	Aug. 14	Aug. 17	Aug. 18	Aug. 20	Aug. 22	*		
68	Aug. 14	Aug. 18	Aug. 19	Aug. 20	Aug. 21	Aug. 23	Died	
69	Aug. 14	Aug. 19	Aug. 21	Aug. 24	Aug. 28	Aug. 31	Sept. 9	
70	Aug. 14	Aug. 17	Aug. 18	Aug. 19	Aug. 21	Aug. 23	*	
71	Aug. 14	Aug. 19	Aug. 21	Aug. 23	Aug. 26	Aug. 29	Sept. 9	
72	Aug. 14	Aug. 19	Aug. 21	Aug. 24	Aug. 27			
73	Aug. 14	Aug. 18	Aug. 20	Aug. 23	Aug. 26	Aug. 30		
74	Aug. 14	Aug. 19	Aug. 21	Aug. 23	Aug. 24	Aug. 28	*	
75	Aug. 14	Aug. 18	Aug. 19	Aug. 21	Aug. 24	Aug. 28	*	
76	Aug. 14	Aug. 18	Aug. 20	Aug. 23.	Aug. 26	Aug. 29	Sept. 7	
77	Aug. 14	Aug. 19	Aug. 23	Aug. 26	Aug. 28	*		
78	Aug. 14	Aug. 19	Aug. 21	Aug. 23	Aug. 28	*		
79	Aug. 14	Aug. 18	Aug. 20	Aug. 23	Aug. 26	Aug. 29	Sept. 8	

* Preserved in alcohol for study immediately after casting molt.

EXPLANATION OF LIFE HISTORY TABLES FOR 1917

FIRST GENERATION

The development of the first generation was not carried on in the insectary due to the fact that we could find no eggs in the field and adults placed in breeding cages died without depositing. Owing to unfavorable weather conditions, there were only a few days on which the adults could be seen flying. However, larvae were gathered in the field about the middle of June and placed in cages where the time of pupation and emergence could be noted.

We observed the first adults flying in the fields on May 13, and the first emergence records of adults from larvae and chrysalids obtained in the field was July 2. This would indicate an approximate period of about 7 weeks for the development of the first generation from the time of egg laying until the emergence of the adult. The pupal stage varied from 7 to 11 days, with an average of 9⅓ days.

SECOND GENERATION

We used 30 individuals for determing the length of the second generation. Of these 13 reached maturity while the remainder died or disappeared from the plants. The average length of the egg stage was 4 days, of the larval stage 18½ days, and the pupal stage 11½ days, making an average of 34 days from time of egg deposition to the emergence of the adult.

THIRD GENERATION

Twenty-three individuals were used to determine the length of the third generation. Of these only eight pupated, the remainder dying from flacherie and other causes. The development of this generation was very irregular and prolonged, owing to unfavorable climatic conditions. The average length of the egg stage was 5½ days, the larval stage 34½ days, and from egg to time of pupation 40½ days. None of the adults emerged from these chrysalids until the following spring.

TABLE IV.—DURATION OF LIFE STAGES OF THE COMMON CABBAGE WORM—SECOND GENERATION: 1917

No.	Larva						Pupa	Adult
	Egg	Hatched	Molt 1	Molt 2	Molt 3	Molt 4	Molt 5	Molt 6
1	July 8	July 12	....	....	....	....	....	....
2	July 8	July 12	July 17	July 20	July 23	July 24	July 30	August 7
3	July 8	July 12	July 17	July 20	July 23	July 24	July 30	August 5
4	July 8	July 12	July 17	July 20	July 23	July 24	July 30	August 7
5	July 8	July 12	July 18	+	....	....	....	....
6	July 8	July 12	July 17	July 20	July 23	July 27	July 31	August 13
7	July 8	July 12	July 17	July 20	July 24	....	....	....
8	July 8	July 12	July 17	July 20	July 23	July 26	July 30	August 7
9	July 8	July 12	July 17	July 21	July 23	July 25	July 30	August 5
10	July 8	July 12	July *	....	....	....	....	....
11	July 8	July 12	July 17	July 20	+	....	....	....
12	July 8	July 12	July 18	July 23	July 24	July 27	July 31	August 13
13	July 8	July 12	July 18	July 23	July 25	July 27	July 31	August 13
14	July 8	July 12	+	....	....	....	....	....
15	July 8	July 12	+	....	....	....	....	....
16	July 8	July 12	July 18	July 21	July 23	July 25	July 30	August 10
17	July 8	July 12	July 18	July 21	July 23	July 25	July 30	August 10
18	July 8	July 12	+	....	....	....	....	....
19	July 8	July 12	+	....	....	....	....	....
22	July 8	July 12	+	....	....	....	....	....
23	July 8	July 12	July 18	July 21	July 24	July 27	August 1	August 14
24	July 8	July 12	*	....	....	....	....	....
25	July 8	July 12	July 17	July 21	July 24	July 27	July 30	August 7
26	July 8	July 12	July 18	July 23	July 25	July 28	July 31	August 13
27	July 8	July 12	*	....	....	....	....	....
28	July ?	July 17	+	....	....	....	....	....
29	....	July 14	July 18	July 21	July 24	July 30	....	....
30	?	July 18	July 24	July 26	July 27	*	....	....
31	?	July 16	July 24	....	....	....	....	....
32	July ?	July 18	July 21	July 24	....	....	....	....

+ Disappeared.
* Dead.

TABLE V.—DURATION OF LIFE STAGES OF THE COMMON CABBAGE WORM—THIRD GENERATION: 1917

No.	Larva						Pupa	Adult
	Egg	Hatched	Molt 1	Molt 2	Molt 3	Molt 4	Molt 5	Molt 6
1	Aug. 8	Aug. 15	Aug. 19	Aug. 23	Aug. 28	Aug. 31	Sept. 28	....
2	Aug. 8	Aug. 14	Aug. 18	Aug. 20	Aug. 24	*	....	....
3	Aug. 8	Aug. 14	Aug. 18	Aug. 20	Aug. 23	Aug. 27	Sept. 5	....
4	Aug. 8	Aug. 14	*	....	....	....	....	....
5	Aug. 8	Aug. 14	Aug. 19	Aug. 24	Aug. 31	Sept. 6	Sept. 19	....
6	Aug. 8	....	*	....	....	....	....	....
7	Aug. 8	....	*	....	....	....	....	....
8	Aug. 8	Aug. 14	Aug. 19	Aug. 22	Aug. 25	Sept. 2	Sept. 17	....
9	Aug. 8	*	....	....	....	....	....	....
10	Aug. 8	Aug. 14	*	....	....	....	....	....
11	Aug. 8	....	*	....	....	....	....	....
12	Aug. 8	....	*	....	....	....	....	....
13	Aug. 8	....	*	....	....	....	....	....
14	Aug. 8	Aug. 14	Aug. 18	Aug. 20	Aug. 22	Aug. 27	Sept. 19	....
15	Aug. 8	Aug. 14	Aug. 18	Aug. 20	Aug. 23	Aug. 27	Sept. 15	....
16	Aug. 16	Aug. 21	*	....	....	....	....	....
17	Aug. 16	Aug. 21	Aug. 24	Sept. 2	Sept. 10	Sept. 17	*	....
18	Aug. 16	Aug. 21	*	....	....	....	....	....
19	Aug. 16	Aug. 21	*	....	....	....	....	....
20	Aug. 16	....	....	....	....	....	....	....
21	Aug. 16	Aug. 21	Aug. 24	Aug. 27	Sept. 1	Sept. 6	Sept. 28	....
22	Aug. 16	Aug. 21	Aug. 24	Aug. 27	Sept. 2	Sept. 8	*	....
23	Aug. 16	Aug. 21	Aug. 24	Aug. 27	Sept. 2	Sept. 8	Sept. 25	....
24	Aug. 23	Aug. *	....	....	....	....	....	....
25	Aug. 23	Aug. 31	*	....	....	....	....	....
26	Aug. 23	Aug. 31	....	....	....	....	....	....
27	Aug. 23	Aug. 31	Sept. 5	Sept. 14	Sept. 18	Oct. 1	*	....
28	Aug. 23	Aug. 31	Sept. 5		....	....	....	....
29	Aug. 23	Aug. 31	*	....	....	....	....	....
30	Aug. 23	Aug. 31	Sept. 6	*	....	....	....	....
31	Aug. 23	Aug. *	....	....	....	....	....	....
32	Aug. 23	....	....	....	....	....	....	....
33	Aug. 23	Aug. 31	Sept. 5	Sept. 14	*	....	....	....

*Dead.

TABLE VI.—LENGTH OF STAGES, 1916–1917—FIRST GENERATION

Stages	1916							1917		
	Maximum		Minimum		Average			Maximum	Minimum	Average
	Series A	Series B	Series A	Series B	Series A	Series B	Average			
Egg	9	7	5	6	7	6	6½	....	....	....
1st instar	12	8	6	5	10	6½	8	....	....	....
2nd instar	8	7	2	3	4	5	4⅔	....	....	....
3rd instar	6	8	2	2	4½	4½	4½	....	....	....
4th instar	10	7	4	2	7½	4	5⅓	....	....	....
5th instar	11	9	3	1	8½	5	6⅓	....	....	....
Larva	39	30	30	24	34	25	29½	*	....	31
Pupa	18	14	10	8	14	9	11	11	7	9⅓
Egg to Adult	57	46	52	38	55	40½	47½	*50	45	47¾

* Conclusions from data gathered in field.

TABLE VII.—LENGTH OF STAGES, 1916–1917—SECOND GENERATION

Stages	1916			1917		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Egg	8	3	5	4	4	4
1st instar	7	1	3	6	5	5½
2nd instar	3	1	2	5	3	3½
3rd instar	3	1	2	4	1	2½
4th instar	4	1	2⅓	4	1	2½
5th instar	9	2	3½	6	3	4½
Larva	21	9	12⅔	30	18	18½
Pupa	9	3	7	14	6	11½
Egg to adult	33	22	26	37	28	34

TABLE VIII.—LENGTH OF STAGES, 1916–1917—THIRD GENERATION

Stages	1916			1917		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Egg	5	3	4⅓	7	5	5½
1st instar	4	1	2	5	3	4
2nd instar	4	1	2⅓	5	2	3
3rd instar	5	1	3	7	2	4½
4th instar	4	2	3	9	4	6
5th instar	11	9	10	23	9	17½
Larva	22	20	21	44	22	34½
Egg to pupation	26	24	25	51	28	40½

FIELD NOTES FOR 1917

The spring of 1917 was rather uniformly cold. During the month of April there was an average daily deficiency of 2.1° Fahrenheit below the normal. The first week of May was also quite cool, but about the latter part of the second week the weather became much warmer.

On May 13 the first butterflies from overwintering chrysalids appeared in the field. On the forenoon of May 16 the adults were flying rather abundantly, but in the afternoon a strong wind came up and only a few could be seen. The following days were also mostly windy and rainy so that only occasional butterflies could be seen.

Although a great many cabbage plants were examined at various times no eggs could be found. Later observations show that the eggs had been only very sparsely deposited on

cabbage but abundantly on wild mustard, horseradish, and garden radish. This was probable due to the fact that the unfavorable weather conditions prevented the majority of butterflies from reaching the cabbage plants, forcing them to deposit eggs on wild plants. Or, possibly the adults of the first generation prefer to deposit on wild plants.

From June 15 to June 19 a total of about 2,000 cabbage and cauliflower plants were carefully examined for the presence of larvae. An average of about 1 larva to every 60 plants was found and never more than 2 to a single plant. Most of the larvae were nearly full-grown although some were only a third to a half grown. One chrysalid was found on June 19.

During the latter part of June and the first few days of July no adults were seen in the field, but on July 4 the adults of the first generation began to appear and by July 15 were quite numerous. On the same date there were a few recently hatched larvae found on plants in the experimental plots.

During the latter part of July only an occasional adult could be seen flying about, but on August 5 the adults of the second generation began to appear and the next day they were flying in large numbers and there were many eggs on the plants.

The latter part of the summer was more or less cool and therefore the development of the third generation was irregular. Whenever the weather was warm enough during September, adults could be seen feeding and laying eggs. About the middle of the month, the weather moderated somewhat and adults became quite abundant. None of these, however, were newly emerged, as their wings were badly frayed and we believe they had been in hiding during the colder weather. We believe that no butterflies emerge from the chrysalids of the third generation until the next spring.

As late as the first part of October large numbers of eggs and young larvae, 2 or 3mm. in length, could be found on the plants, but as far as could be determined most of these eggs did not hatch and none of the small larvae ever matured. An occasional adult was seen in the field even as late as October 15.

SEASONAL HISTORY

The published records concerning this insect indicate that it is capable of continuous development, the number of gener-

ations within a year being controlled by climatic conditions. Our observations show quite clearly that only three generations a year may normally occur in the northern United States.*

At Madison, where the life history studies were carried on, larvae just hatched to full-grown may be found from May until after freezing weather begins in the fall. Little or no development takes place after the temperatures get below 60° Fahrenheit in the fall and all larvae that have not changed into chrysalids by November 1 perish.

A definite relationship between weather conditions and the development of this insect is clearly evident, as shown by the accompanying chart and life history tables.

In Table 1 we have given the mean temperatures for the growing season of 1916 and 1917. Except for the month of June there was a considerable difference in temperatures between the two seasons. Our breeding records show that growth was much more rapid in 1916 than in 1917 but in each season we secured only three complete generations.

We also found that chrysalids in protected spots on the sunny side of a building develop a month earlier in the spring than those in shaded places. This is probably the reason for the emergence of a few individuals early in the season.

In 1916 few butterflies were to be seen in the field until about the first week of May. In 1917 it was the third week in May. In 1916 the first eggs were found May 6. Temperature records show some relationship here in that during the last half of April, 1916, it was generally warmer than during the same period in 1917. In May, 1916, the temperature reached 58° on the second and rose to 77° on the seventh. In 1917 a temperature of 60° was reached only three times up to May 13. On May 14 it rose from 62° to 72° and increased to 82° on May 17. These increased temperatures being so close to the main emergence of butterflies and the beginning of egg deposition indicate that emergence and egg deposition are very closely correlated with temperature conditions.

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* Several writers have indicated the time required for the development of the different stages but we cannot find that any one has previously given a complete record of the development of this insect. We are, therefore, unable to draw any definite conclusions regarding the development of this insect in the southern part of the United States.

TABLE IX—MEAN MAXIMUM, MEAN MINIMUM, AND MEAN MONTHLY TEMPERATURES FOR 1916 AND 1917

		April	May	June	July	Aug.	Sept.	Oct.
Mean maximum temperature	1916	53.8	66.4	69.9	88.9	82.4	68.3	58.4
	1917	50.5	60.7	69.6	80.7	76.3	68.8	47.1
Mean minimum temperature	1916	36.8	48.2	53.6	67.3	63.2	50.6	40.0
	1917	34.3	43.4	54.0	63.8	57.8	51.2	32.9
Mean monthly temperature	1916	45.3	57.3	61.8	78.1	72.8	59.4	49.2
	1917	42.4	52.0	61.8	71.8	67.0	60.0	40.0

It is still to be noted that in 1916 July was much warmer than in 1917 and in our breeding cages the second generation of that year matured in an average of 23 days while in 1917 an average of 34 days was required. In the third generation the larvae matured in an average of 28.58 days in 1916 and 40.5 days in 1917.

Following the spring generation an entire lack of butterflies is noticed for a period of a week or ten days. However, early in July the second generation appears and the emergence of butterflies is more or less continuous the rest of the season. Due to better food and warmer temperature, the second generation makes more rapid progress than the first. The different stages occur in quick succession and from ten days to two weeks is sufficient time for a thriving larva to mature and pupate. The pupal period is correspondingly short, requiring only from six to nine days for completion.

While the emergence of butterflies in the summer is continuous up to fall, the emergence of a third brood of butterflies is fairly noticeable. During the first week in August, 1916, the butterflies of the third generation appeared in great numbers in the field, indicating quite clearly the maximum period of emergence. No adults emerged from the chrysalids which we succeeded in rearing from third generation butterflies.

LIFE OF THE INDIVIDUAL

The Egg.— (Figure 5 A.) The eggs are deposited singly on either surface of the leaves, generally on the under surface of the outer leaves, without apparent regularity. They are always deposited so that they stand at right angles to the leaf surface and can be seen with the naked eye. When first deposited they are light greenish yellow in color, later turning to a dark lemon yellow. In shape they are somewhat like an elongated jug without a handle and are about as large as a small seed. The widest diameter is about one-third of the distance from the top to the bottom where the egg measures approximately 0.45 mm. in diameter. The diameter at the base is about 0.35 mm., at the top .09 mm.; height from base to apex 0.9 mm. to 1 mm. The egg tapers gradually from the upper third to the base and acutely from that point to the apex, where it ends in a flattened top. Twelve longitudinal ribs approximately 1 mm. apart at the widest point with a series of transverse markings around the egg tend to give a basket-like appearance. The eggs hatch in from 3 to 10 days, depending upon the temperature.

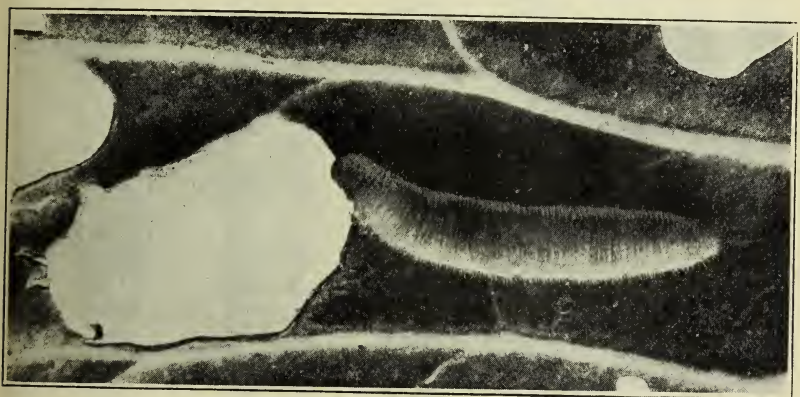

FIG. 4.—CABBAGE WORMS EAT SOFT TISSUE BETWEEN VEINS

The young and larvae eat small holes in the leaf surface and feed around the edges of these, clear up to the veins.

Egg deposition.—The female alights near the edge of the leaf and curves the abdomen under until the tip encounters the leaf surface. The tip of the abdomen is then firmly pressed

against the leaf for a second and then withdrawn, leaving the egg standing on end.

One female placed in a cage immediately after copulation laid a total of 238 eggs during a period of 5 days,—125 eggs the first day, 75 the second, 37 during the third and fourth, and 1 on the fifth.

The Larva.— (Figure 5 B.) When the young larva is fully developed in the egg it begins cutting its way out near the top of the shell. At first a tear is made and then the larva eats

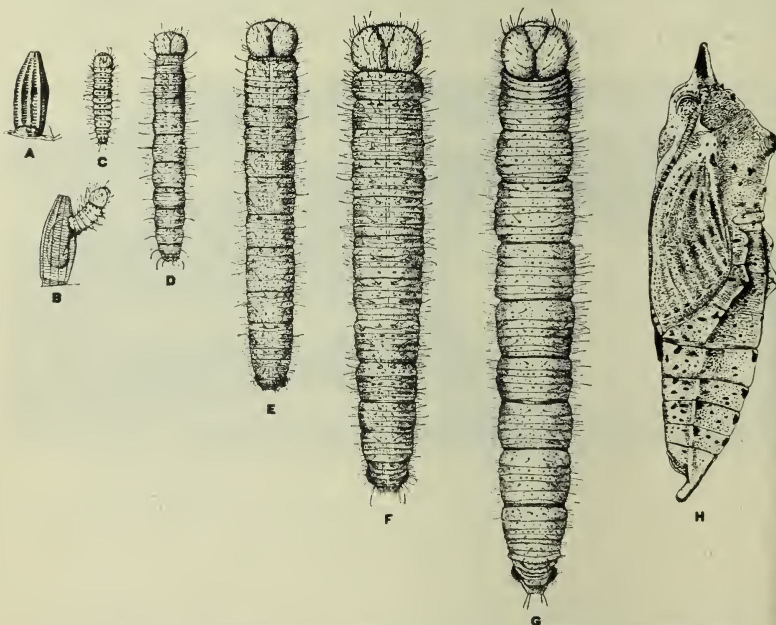

FIG. 5.—THE DIFFERENT STAGES OF THE LARVA OF THE COMMON CABBAGE WORM

A. The egg.
B. The young larva breaking out of the egg.
C. The larva: first stage.
D. Second stage.
E. Third stage.
F. Fourth stage.
G. Fifth stage.
H. The chrysalis.

away the egg shell until an opening is made large enough to push the head through. Its head being larger than the rest of the body the larva has little trouble escaping from the shell after the head is out.

As soon as the larva is out of the shell it turns around and beginning at the edge of the opening feeds on the shell until it is completely gone. About two hours are required for the emergence of the young larva and the destruction of the shell. Then the larva begins feeding on the plant tissue and eats out

little areas on the underside of the leaf. When full-fed in any stage it fastens itself to the leaf with a few threads and prepares to molt. In molting the larva must do considerable writhing before the head can be squeezed out of the old skin. It molts five times, so that there are five larval stages or instars. With the fifth molt the larva changes to the pupal or chrysalid stage.

During the first and second instars the young larvae do not move about to any large extent and usually continue feeding close to the point of emergence. Following the second molt they move about more and feed mostly on the edges but not necessarily on the outside edge (fig. 4). We have made observations to try to determine if there were any regularity in the habits of the older larvae but without distinct result. Larvae may be found on all parts of the plant both day and night and although a number may be found feeding at the base of the leaves and boring into the head of the cabbage, equal numbers may be found on the outside leaves and even resting in plain sight on the upper surface.

Larva, first stage. (Figure 5 C.) Body a very pale greenish yellow to white transparent, which becomes green as soon as they have eaten; length about 1.5 mm. Head a pale greenish yellow with dark slightly curving hairs of variable length; about .35 mm. broad; ocelli black, mouth parts and antennae pale to transparent yellowish, mandibles edged with brown and teeth distinctly brownish; dark flecks or pits on the head; body cylindrical, greenish yellow; segments bearing whitish warts giving rise to colorless, slightly arcuate hairs, the club of the upper rows being slightly larger than that of the others; spiracles pale yellow edged with black; legs and prolegs color of body; claws on the prolegs small and colorless; body at first .25 mm. wide but later becomes as wide as the head except just behind its base.

Larva, second stage. (Figure 5 D.) Head and body a pale green with a narrow, yellowish, dorsal stripe; mingled black and white hairs arise from small warts on the head; ocelli black; mouth parts and antennae green; edge of mandibles tinged with black or fuscous; abdominal segments with white warts arranged in subdorsal rows giving rise to black, tapering, blunt-tipped hairs; whole body sprinkled with fuscous greenish warts giving rise to short black hairs, or moderately long, tapering and deli-

cately clubbed pale hairs, the warts being arranged in seven transverse rows on each segment, the anterior and posterior pairs being closer together than the others; a sub-stigmatal anterior white wart gives rise to a pale hair. Spiracles pale yellow with blackish ring; legs, prolegs and claws color of body. Length usually about 9 mm., breadth 1.5 mm.

Larva, third stage. (Figure 5 E.) The third stage is about the same as the second. Each segment bears one or two small yellow spots along the stigmatal line. Length about 14 mm., width 2. 5 mm.

Larva, fourth stage. (Figure 5 F.) Head the color of the body with many hair-bearing warts, a few white; ocelli black; mandibles greenish, brownish to black at the edge; body green with a narrow dorsal longitudinal band of green or lemon-yellow; body covered with large and small wartlets giving rise to fine white or fuscous hairs, the larger ones in transverse rows; also three longitudinal rows of white wartlets, each one bearing a fuscous hair; a subdorsal row in the anterior of each segment; a stigmatal row placed ventrally; spiracles grayish, edged with black; legs green, claws blackish; prolegs, green. Length about 20 mm., breadth about 4.5 mm.

Larva, fifth stage. (Figure 5 G.) The fifth stage is similar to the fourth stage and requires no additional description.

The Chrysalis. (Figure 5 H.) When full-grown the larvae begin crawling about hunting a favorable place for pupation. Many pupate on the plants themselves but the majority of chrysalids are found on adjoining fences, buildings, trees, and, in fact, any object which they can ascend. As they begin to pupate they spin a few silken threads which they fasten to the object beneath them. They then fasten the tip of the abdomen with silken threads and make a girdle which surrounds the body about midway. During this time the body begins to shorten and thicken at the thorax, and with much wriggling the last larval skin is cast off.

The chrysalids of the summer generations are greenish to greenish grey in color and do not show distinctly all the determining characteristics. The overwinter chrysalids are more of an ashen grey without the greenish tints of the summer forms. The thoracic and abdominal projections are edged with reddish brown, the remaining portions being only sparsely dotted with black. The dorsal surface is brownish yellow with

a greenish tinge, abundantly speckled with minute, black circular punctures arranged somewhat in transverse rows on the abdomen and often connected with fine, black lines giving the whole chrysalis a fuscous speckled appearance.

The Butterfly. (Figure 6.) The general color is white with grey to black markings and white or yellow beneath except two black spots on the underside of the front wing. The female can be distinguished quite easily from the male by the two black spots on the forewing, the male having but one.

Most of the butterflies that were caught early in the spring were males. It would seem that the males emerged slightly earlier than the females. This supposition was supported by

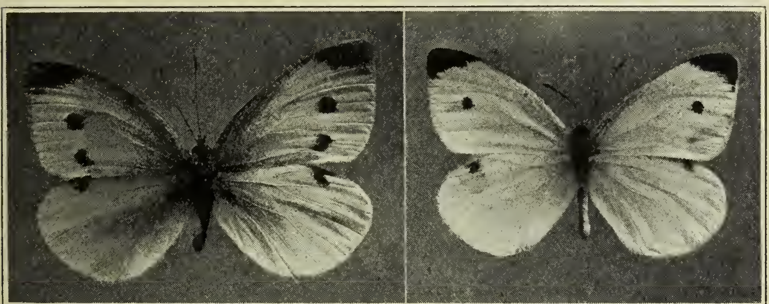

FIG. 6.—ADULTS OF THE COMMON CABBAGE WORM
Left—female. Right—male.

data obtained from a cage in which 250 individuals of the second generation were reared. A large number of males emerged first while the females did not emerge in numbers until several days later.

NATURAL CONTROL

If it were not for the natural agencies which help to control the cabbage butterfly, it would indeed be a most serious pest.

Birds, spiders, insects, bacteria and fungi destroy uncountable millions of them each year and many are destroyed through unfavorable climatic conditions.

Few records have been made of the birds that feed on them but the chipping sparrow, English sparrow and house wren are known to eat a great many. Neither are there records on

destruction by spiders, but Fitch, 1870, records two species of spiders* as feeding on them and indicates that a great many are destroyed in this way. At the time of his writing he had not noticed any internal parasites but he noticed a number of bugs of the order Hemiptera feeding on the larvae.

In Wisconsin we have observed two hymenopterous parasites, *Pteromalus puparum* and *Apantales glomeratus,* which destroy great numbers of the larvae and pupae each year. Flacherie, a bacterial disease sometimes known as "wilt," is also prevalent and in some years many diseased larvae may be found hanging to the leaves and rotting away. This disease has caused us much trouble in the insectary and destroyed many of the larvae used for breeding data.

Pteromalus puparum L. is the most common and the most efficient parasite. Much has been said regarding the particular stage of the caterpillar attacked by this insect and no doubt *P. puparum* and *A. glomeratus* have been much confused by observers. Mr. Pickett has made numerous observations on the attack of these two parasites and has found that *P. puparum* attacks both the larvae in the later stages and the chrysalids just after the last larval skin is cast. *A. glomeratus* attacks the larvae in the younger stages and emerges before the pupal stage is reached.

Neither of these parasites was supposed to be present in America previous to the importation of the cabbage worm and *Pteromalus puparum* was not noticed until 1870 or 1871 and *Apanteles glomeratus* until 1880.

Parasitization by both of these insects varies for the different generations. They are not numerous in the spring but increase rapidly through the summer months and usually parasitize a very high percentage of the larvae during August. At one time in August, 122 nearly mature larvae were gathered to get data on the number parasitized. Of these 101 were parasitized, 14 died from unknown causes and only 8 developed into butterflies. The lowest number of parasites secured by us from any one of these chrysalids was 17, and 67 was the greatest.

In parasitizing the caterpillars, the adults alight on the back of the caterpillar near the terminal segments usually with the head toward the head of the caterpillar. In this position the

* *Theridion brassicae* and *Theridion hypophyllum.*

ovipositor is suddenly thrust beneath the skin of the caterpillar and an egg deposited. The stung caterpillar becomes agitated and usually jerks the head back toward the spot of oviposition before settling down again. The parasite then lays another egg in the same manner with like results.

The parasitized chrysalids are darker in appearance than unparasitized ones and the skin or integument is hard and brittle. Parasitized chrysalids can always be distinguished from living ones by touching the abdominal portion. If parasitized, this part will be hard and rigid. If the chrysalis is alive, it will be soft and flexible. It has not been determined how many eggs one parasite will lay in a single larva. As many as 139 adult parasites have been found emerging from a single chrysalid and 40 to 50 are common.

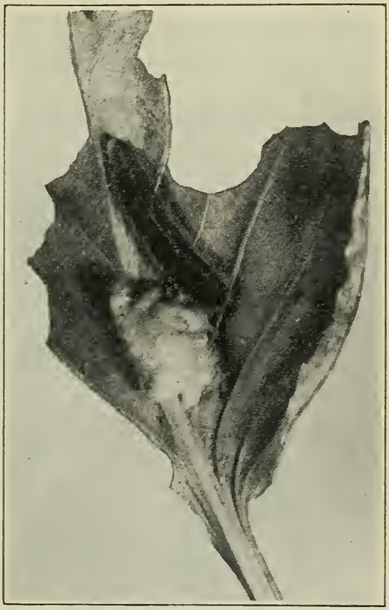

FIG. 7.—PARASITES DESTROY MANY WORMS

Larva of the cabbage worm destroyed by a parasite *(Apanteles glomeratus)*.

Apanteles glomeratus is thought not to be a native species of North America and special importations were made in the early '80's. It seems quite likely that the species must have become esestablished before that time because Thomas in writing of *(Apanteles) Microgastis glomeratus* in 1880, makes the following statement:

"Although this species, so far as I am aware, has not yet been observed infesting these cabbage worms in this country, yet cocoons somewhat similar to those made by it have been found about the caterpillars of *P. rapae*."

Chittenden, 1905, records it as having destroyed 60 per cent of the larvae in a batch collected at Washington, D. C., in August. In another collection made during the first week in September every larva was destroyed by the same parasites.

Matheson has studied the life history of this species to some extent and gives notes (1907) on general life history and habits. He found that about 50 per cent of the larvae of *Pieris rapae* taken in July and August were parasitized and in September and October this had increased to an average of 60 to 75 per cent.

The adults of *Apanteles glomeratus* are very noticeable among the cabbage larvae and may be readily seen as they settle to oviposit on them. In parasitizing the larva, the female searches out a young one in the second or third stage, bends the abdomen almost at right angles, rushes on the caterpillar and drives the ovipositor through the body wall. It is not uncommon to see two or three females ovipositing in the same larva at the same time. The time required for oviposition is from 10 to 15 seconds and Matheson, 1907, found that from 15 to 35 eggs were deposited during each egg laying period. The eggs are said to hatch in from 3 to 4 days and the young larvae feed on the fatty tissue of the body without injuring the vital parts. They mature within 8 to 12 days, and cutting through the skin they escape to the outside, where each individual constructs a little yellowish silken cocoon in which it pupates. The time spent in spinning a cocoon is not over 45 minutes and often less. The number of parasites from a single larva varies greatly; usually there are from 20 to 30 although as many as 140 have been recorded. In the field the parasitized larvae turn to a dark yellow color. The dorsal stripe widens and becomes more distinct. They also have a distinct puffy and unhealthy appearance.

FIG. 8.—BACTERIA WILL ALSO DESTROY WORMS

Many larvae are killed on the plants by a disease known as wilt, or flacherie.

Flacherie or "wilt" (figure 8) usually does not become ap-

parent in the larvae until after the fourth molt. The larvae then appear natural but do not eat, and upon being touched they are found to be soft and often dead, though apparently alive. Following this stage of the disease, the skin begins to shrink, the body turns brown, then black, and finally dries up.

A number of additional insects such as wasps, plant bugs, wheel bugs and Tachinid flies prey on the cabbage butterfly either in the larval or adult stage but do not play any great part in their control in Wisconsin.

REMEDIES

In the history of nearly every insect pest there has been a long series of attempted methods of control and as a rule effective measures have been determined upon only after many substances and methods have been tried out. In each case many worthless and a few effective and practical remedies are produced. This was especially true prior to the development of arsenate of lead, because no effective remedy was known for chewing insects except paris green and london purple. These were considered to be dangerous to the consumer and were avoided except in cases of extreme necessity. At the same time continued attempts were being made to find a poison that would be effective against insects and would not remain on the plants in sufficient amounts to poison the consumer.

We have made a study of the various remedies tried out and have summarized the more important ones as follows:

The earliest recommendations for the control of the cabbage butterfly were to pick off the larvae, gather the chrysalids and catch the butterflies in nets. Curtiss, a British entomologist recommended, "When they attack the seed crop, shaking the stems may prove useful providing the ducks are to follow and pick up the caterpillars." He suggested the use of hellebore but did not try it.

Fitch, 1870, also recommended employing the children to catch the butterflies and the placing of elevated boards between the rows for the pupation of larvae. When the chrysalids were formed, they were to be gathered, then destroyed. He did not think that hellebore had much value.

A Mr. Quin reported, 1870, that a mixture of carbolic powder, superphosphate and lime destroyed the caterpillars. The

carbolic powder appeared to be a sawdust impregnated with carbolic acid. He tried salt but found that it was not efficient.

Other remedies suggested were hot water somewhere below 200° F., salt, brine, powdered lime, ashes, lye and alder decoction. Thomas, 1879, tested these out and found that they were unsatisfactory. He mentioned the use by others of a decoction of dog fennel and knotweed and the use of black pepper with reported favorable results.

Forbes, 1882, made a series of tests against the larvae with hot water, powdered pyrethrum, tobacco smoke, sulfur, bisulfide of carbon, kerosene emulsion, saltpeter, brine and tar water. He found pyrethrum to be the only one of these remedies which was both effective and practical to use. Hot water in strengths that would kill the insects also killed the plants. Tobacco smoke was found impractical for field use. Sulfur killed the plants and did not kill the worms.

The use of arsenicals in the form of paris green and london purple were tried out as early as 1870 by Riley and were found to be effective but he considered them dangerous. Gillette, 1889, recommended the use of paris green or london purple in 20 parts of flour, plaster, or plaster paris, dusted over the plants while the dew was still on them. He recommended that pyrethrum be used in the place of paris green when the heads began to form. In 1891 he used oxide of silicates dusted over the plants and found it to be fairly effective. He estimated that when the outer leaves were removed from cabbage sprayed with paris green, a person would have to eat 30 entire cabbages at one time to get a poisonous dose.

M. H. Beckwith, 1889, states that paris green or london purple should never be used upon cabbage.

Sirrine, 1894, refers to Fitch's plan of catching the butterflies and believes that this is the most practical preventive that can be used. He estimates that the progeny from a single female might in the third brood reach 125,000 female butterflies. He discusses the different materials that had been used previous to that time and concludes that paris green and london purple are the most reliable but they should not be sprayed on the plants after they are half grown. He conducted a series of experiments and notes that neither road dust nor flour will prevent injury from free arsenic if dew is on the plants. The addition of water and slaked lime will prevent burning when

the poison is applied as a wet spray and also aids in making the poison adhere to the plants. He recommends mixing 1 part of the poison to 15 or 20 parts of flour, road dust or land plaster for a dry spray; and for a wet spray:

Paris green or london purple ----------	1 pound
Lime unslaked ------------------------	16 pounds
Water to make -----------------------	160 gallons

He suggested the use of "gypsine" or arsenate of lead, which was then being used by the Gypsy Moth Commission of Massachusetts for the control of the gypsy moth.

FIG. 9.—IT PAYS TO SPRAY

Plants protected by spray form perfect heads; unprotected plants are often completely destroyed.

SPRAYING FOR CABBAGE WORMS

During our investigations we have come to the conclusion that the arsenicals are by far the most satisfactory materials to use in the control of cabbage worms and other insects which in the "worm" or larval stage feed on cabbage.

To determine the comparative efficiency of the different arsenicals now on the market we conducted a series of trials with paris green, calcium arsenate, zinc arsenite and lead arsenate. Because of the peculiar waxy surface of the cabbage foliage, water alone rolls off in large drops and it is necessary to use a "sticker" of some kind. We have tried out a number of differ-

ent materials such as Good's resin soap, different solutions of molasses, alone and with lime, and ordinary laundry soap. We have been most successful with common resin laundry soap, which causes the poison to spread evenly and set well. Complicated preparations are not always satisfactory and do not give any better results than soap.

FIG. 10.—SPRAYING CABBAGE PLANTS TO KILL CABBAGE WORMS

Sprayers of this type are not costly and are practical for use in the garden and on the small truck farm.

As a rule wet sprays are preferable to dusting, but in small garden patches dusting may be resorted to if the gardener does not have a sprayer. The dust may be sifted through coarse sacking or a tin can with holes punched in the bottom. A practical garden sprayer with the pump in the handle is shown in figure 10. In figure 11 a dusting apparatus is shown which works exceedingly well. **Dust sprays should always be applied early in the morning while the dew is still on the plants.**

If a dust spray is used, mix thoroughly 1 pound of poison with 10 pounds of air-slaked lime or land plaster.

In Series II of the experimental plots in which comparative tests of zinc arsenite, arsenate of lead and calcium arsenate are shown, arsenate of lead and calcium arsenate are proved to be satisfactory spray for the control of the cabbage worm while arsenite of zinc seems not to have been satisfactory. Further trials with this material are necessary. Powdered lime alone or mixed with tobacco dust did not give good results.

FIG. 11.—DUSTING CABBAGE PLANTS TO POISON CABBAGE WORMS
This type of dusting machine covers the plant thoroughly and gives efficient control.

MATERIALS TO USE

If arsenate of lead, calcium arsenate and paris green are all available, the one that costs the least should be used. Arsenate of lead and calcium arsenate in powder form should be used at the rate of 1 pound of material to 50 gallons of water. In paste, just twice as much, or 2 pounds to 50 gallons, must be used, as paste contains 50 per cent water.

Paris green may be used at the rate of ¾ of a pound to 50 gallons of water.

In order to make any poison spread and stick well when spraying cabbages, add 1 pound of common laundry soap to each 50 gallons of spray.

WHEN TO SPRAY

All plants should be dipped in a solution of calcium arsenate or arsenate of lead, 1 pound to 50 gallons of water at the time of setting out in the field. Early cabbage should be protected by spray when the plants are young because of possible flea beetle injury. Cabbage worms are usually not so bad on early as on late varieties and the growers can spray or not, as it seems necessary. On late cabbage two or three applications of spray are necessary to secure the best results. Normally two applications will suffice but in years when the cabbage worms are unusually abundant a third application may be applied at the discretion of the grower. Two applications made as indicated below should give efficient control:

1. Spray plants thoroughly with calcium arsenate or arsenate of lead 1 pound to 50 gallons of water plus 1 pound of resin laundry soap, from July 10 in the southern part of the state to July 20 in the northern part.

2. Spray again with the same materials about four to five weeks after the first application.

IS IT DANGEROUS TO EAT CABBAGE SPRAYED WITH POISON?

Whether or not sprayed cabbage is dangerous to eat is a very important question in Wisconsin because of reasons previously mentioned and we have taken pains to determine this both for the head and the outer leaves. If ordinary precautions are used in cleaning cabbage, there is no danger in eating heads that have been treated with poison. *Cabbage grows from the inside and all of the leaves* formed early in the season and the ones receiving the most spray are stripped from the head at the time of picking. When a head of cabbage reaches the housewife, there is but one leaf left that might have received any spray during the summer and this with others is usually removed during the cleaning process.

From the experimental plats, Series II, we selected one head of cabbage from each of plats 2, 3, 7, 8, 9, 11 and 6, the last being a check and unsprayed. Each head was prepared as though it were to be sent to market and then turned over to the agricultural chemistry department for analysis.* No trace

* The analyses noted in this bulletin were secured through the kindness of E. B. Hart, Department of Agricultural Chemistry.

of arsenic was found on any head. An analysis of the outer leaves, however, showed that a considerable amount of arsenic was present on those parts of the plant and care should be used in feeding the treated leaves to stock.

SPRAYING EXPERIMENTS FOR CABBAGE WORMS

Series I. The purpose of these experiments was to determine the comparative value of Black-Leaf-40 and arsenate of lead for the control of worms on cabbage.

Black-Leaf-40 is unsatisfactory because it rolls from the leaves as it is put on and even when soap was used the liquid did not seem to wet the larvae sufficiently to kill them except where it collected in the hollows at the base of the leaves.

As was to be expected, arsenate of lead was efficient except when combined with Good's resin soap, which is a material made especially as a sticker on cabbage and similar plants. The resin soap was dissolved in the water and the poison added in the usual manner. The spray appeared to spread out on the plants well but for some reason the poison did not appear to affect the larvae.

Series II. The purpose of these experiments was to compare zinc arsenite, lead arsenate, paris green, and calcium arsenite as poisons and also to see if tobacco dust or lime might prove effective.

Arsenate of lead, calcium arsenate and paris green were shown to be effective both as wet and dust sprays. Arsenate of lead used as a dust spray was even effective when used at the rate of 1 pound to 50 pounds of lime.

We are unable to account for the poor results obtained from arsenite of zinc and believe that the material used was defective in some way. Further experiments are necessary to get reliable data on this material.

Tobacco dust and lime were not at all effective.

TABLE X.—SPRAYING EXPERIMENTS FOR CABBAGE WORM 1916 (SERIES I)

Plat No.	No. of heads	Spray used	Infestation at time of spraying	Spray applied	Remarks
1	50	Black leaf—40 1-1000	Many worms present, leaves badly eaten	Aug. 8	Examinations made daily up to Aug. 18. A few larvae killed but net results poor.
2	50	Black leaf—40 1-1000 + soap 1-50	" "	Aug. 8	Examinations made daily up to Aug. 18. Could not see that net results were better than in No. 1.
3	10	Check	" "	Aug. 8	Sprayed with water alone. Examinations made at same time as on sprayed plots. Cabbages heavily infested.
4	50	Black leaf—40 1-1000	" "	Aug. 16	Somewhat better results obtained than in No. 1. On Aug. 21 a number of decaying larvae found. May be flacherie. Live larvae numerous
5	50	Black leaf—40 1-1000 + soap	" "	Aug. 16	Conditions same as in experiment 4. Soap solution spreads better.
6	10	Check	" "	Aug. 16	Observations made daily. Plants continued to be heavily infested and badly eaten.
7	50	Black leaf—40 1-500 + soap	" "	Aug. 21	Observations made from Aug. 22 to 31. A few larvae died but many alive and feeding on last date.
8	50	Black leaf—40 1-500	" "	Aug. 21	Results the same as in plat 7. Black leaf—40 not considered sufficiently effective for field use.
9	10	Check	" "	Aug. 21	Observations made daily. Plants continued to be heavily infested and badly eaten.
10	50	Lead arsenate powder, 1-50 + soap 1 lb.	" "	Aug. 17	Aug. 18 larvae very sick. By Aug. 21 all larvae dead except a few newly hatched ones on under side of the leaves.
11	50	Lead arsenate powder, 2-50 + soap 1 lb.	" "	Aug. 17	Conditions same as in experiment 10.
12	50	Lead arsenate powder, 1 to 3 lbs. flour used dust gun	" "	Aug. 21	Larvae nearly all dead on the following day. Aug. 23 examination showed no living larvae present on treated plants.
13	50	Lead arsenate powder, 1 to 3 lbs. lime used dust gun	" "	Aug. 21	Conditions same as in experiment 12.
14	50	Lead arsenate powder, 2-50 — Good's resin soap	" "	Aug. 19	For some reason was not effective. Observations made up to Aug. 25. Larvae still alive and feeding on plants. Results doubtful.

TABLE XI.—SPRAYING EXPERIMENTS FOR CABBAGE WORM, 1917. (SERIES II.)

Plat No.	No. of heads	Spray used	Infestation at first spraying	No. of sprays	Dates of application					Results
					1st	2nd	3rd	4th	5th	
1	6	Zinc arsenite powder, 1 to 50+1 lb. soap.	Large number of worms. Outer leaves badly eaten.	5	Aug. 7	Aug. 17	Aug. 28	Sept. 5	Sept. 10	Injury practically as severe as in untreated plants. Head unfit for market.
2	6	Lead arsenate powder, 1 to 50 + 1 lb. soap.	" "	5	Aug. 7	Aug. 17	Aug. 28	Sept. 5	Sept. 10	Complete control. Heads in perfect condition. Outer leaves clean.
3	6	Paris green, 1 to 50 + 1 lb. lime and 1 quart molasses.	" "	5	Aug. 7	Aug. 17	Aug. 28	Sept. 5	Sept. 10	Complete control. Heads in perfect condition. Outer leaves clean.
4	36	Zinc arsenite powder, 1 lb. to 10 lbs. lime.	" "	4	Aug. 9	Aug. 14	Aug. 29	Sept. 10	....	Poor control. Nearly every head unfit for market.
5	36	Lead arsenate powder, 1 lb. to 10 lbs. lime.	" "	4	Aug. 9	Aug. 14	Aug. 29	Sept. 10	....	Good control. Heads perfect, although outer leaves were somewhat injured.
6	10	Unsprayed—check.	" "	0	....	....	....	....	....	All heads unfit for market.
7	10	Calcium arsenate paste, 2 to 50, + 2 qt. molasses.	Large number of worms. Outer leaves badly eaten. Forming head attacked.	2	Aug. 22	Sept. 10	....	....	....	Satisfactory control. None of heads unfit for market. Although outer leaves were somewhat injured.
8	10	Calcium arsenate p wdr, 1 to 50, + 2 qt. molasses.	" "	2	Aug. 22	Sept. 10	....	....	....	Satisfactory control. None of heads unfit for market. Although outer leaves were somewhat injured.

TABLE XI—SPRAYING EXPERIMENTS FOR CABBAGE WORM, 1917. (SERIES II.)

Plat No.	No. of heads	Spray used	Infestation at first spraying	No. of sprays	Dates of application					Results
					1st	2nd	3rd	4th	5th	
9	11	Calcium arsenate powder, 1 lb. to 5 lbs. lime.	Large number of worms. Outer leaves badly eaten. Forming head attacked.	2	Aug. 22	Sept. 10	....	....	....	Good control. Heads perfect. Outer leaves only slightly injured.
10	10	Calcium arsenate powder, 1 lb. to 10 lbs. lime.	" "	2	Aug. 22	Sept. 10	....	....	....	Good control. Heads perfect. Outer leaves somewhat injured.
11	10	Zinc arsenite powder 1 lb. lb. to 5 lbs. lime.	" "	2	Aug. 22	Sept. 10	....	....	....	Poor control. Every head unfit for market.
12	11	Calcium arsenate paste, 2 to 50, + 3 lbs. lime and 2 quarts molasses.	" "	2	Aug. 22	Sept. 10	....	....	....	Good control. Heads perfect. Outer leaves somewhat injured.
13	12	Calcium arsenate paste. 2 to 50, + 1 lb. soap.	" "	2	Aug. 22	Sept. 10	....	....	....	Complete control. Heads in perfect condition. Outer leaves clean.
14	10	Zinc arsenite powder, 1 to 50 + 1 lb. soap.	" "	2	Aug. 22	Sept. 10	....	....	....	Poor control. Most of heads unfit for market.
15	15	Fine tobacco dust 1 lb. to 3 lbs. lime.	" "	2	Aug. 22	Sept. 10	....	....	....	Seemed to have no effect.
16	15	Lime dust.	" "	2	Aug. 22	Sept. 10	....	....	....	Seemed to have no effect.
17	15	Coarse tabacco dust 1 lb. to 3 lbs. lime.	" "	2	Aug. 22	Sept. 10	....	....	....	Seemed to have no effect.
18	15	Lead arsenate paste, 2 to 50, + 1 lb. soap.	Large number of worms. Most of leaves eaten off.	1	Sept. 8	....	....	....	....	All worms killed. New leaves came out clean and uninjured.

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Frost Necrosis of Potato Tubers

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CONTENTS

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The late or main crop of potatoes as grown and handled in the northern tier of states is likely to be exposed to freezing temperatures from the last month preceding digging through all the stages of harvest, transportation, storage, and delivery to the ultimate consumer. The danger of freezing injuries is one of the most serious risks of commercial potato growers and dealers and the problems of the transportation companies are also seriously complicated thereby.

In 1917, when freezing temperatures occurred very generally through the northern states before or during potato harvest, the resultant losses probably constituted a greater toll upon the Wisconsin crop than all other disease factors combined, and even in 1918, when the climatic conditions were especially favorable, freezing injuries were common and serious. These consisted not only in the immediate loss of tubers frozen in the field or warehouse, but also in the later appearance in storage of potatoes exhibiting the more obscure freezing injuries.

Frost necrosis distinguished from other injuries. It is important at the outset to point out the general characters of frost necrosis that it may be distinguished from other types of injury. It is well known that when once frozen solid the potato tuber is killed and collapses immediately upon thawing. If, however, the exposure to freezing temperatures is moderate or of short duration, it often happens that only a portion of the tubers are thus frozen solid and collapse, the rest remaining unaffected as far as external appearances indicate. If, however, such superficially sound tubers are cut open, various evidences of internal injury will be found in at least some of them. In

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[1] The term frost necrosis is synonymous with the term freezing necrosis used by Link and Gardner in an unpublished manuscript. (See footnote 1, page 20.) The writers agree with them that frost necrosis is a local or restricted freezing injury which results from exposure to temperature sufficiently low to cause ice formation in the tissues and is thus distinct from chilling injury which results at temperatures not low enough to induce ice formation in the plant tissues. The writers use the term frost necrosis rather than freezing necrosis since frost necrosis has been used in a previous publication (Jones, L. R. and Bailey, E., Frost necrosis of potato tubers. Phytopath. 7. 71-72, 1917).

most cases such injuries remain strictly internal and hence, if the potatoes are marketed their defects are not detected until the potatoes reach the ultimate retailer or consumer.

The irregular occurence and distribution of tubers which show such internal lesions of frost necrosis makes them difficult to sort out in storage lots. Naturally, potatoes frozen during harvest or transportation become mixed with the sound ones, but it is a surprising fact that when storage chambers are subjected to the same freezing temperatures and uniform conditions of ventilation, certain scattered individual tubers will be injured and others not. This individual susceptibility of potatoes to freezing injuries, combined with the still more confusing fact that frost necrosis is often mistaken for pathological conditions arising from other causes, makes it important that there be a further understanding both of the conditions and nature of freezing injury to potato tubers. This is especially needed at this time because of two recent coordinated developments involving critical consideration of potato tuber maladies. On the one hand is the movement for the state inspection and certification of potato seed stocks, on the other is the development of the national market inspection service. In both cases it is necessary to differentiate frost necrosis from other types of tuber injury or disease, especially the non-parasitic "net-necrosis" and the Fusarium "ring necrosis." Indeed, it was because of the evident confusion of frost necrosis with certain of these other types of injury that the senior author's attention was first directed to this problem. Frequently within the past four years potatoes showing distinct symptoms of ring or net necrosis have been found in storage cellars where it was definitely known that they were generally sound when stored and had been subjected to freezing temperatures while in the cellar. One striking example of typical net necrosis occurred in a certain lot of selected exhibition potatoes shown at the meeting of the Wisconsin Potato Growers' Association in 1914. The exhibitor was confident that the tubers were normal when he started from home but they had been subjected to freezing temperatures in transit. Similar conditions were found in several lots of potatoes in the exhibition of 1918. The matter presented so much of practical as well as scientific interest that further observations have been supplemented by careful

experiments to determine the effects of various freezing temperatures upon potatoes.

Previous publications. Several previous publications have embodied the results of more or less extensive investigations upon freezing injury to potatoes. The most valuable of these is that of Müller-Thurgau (4, 5, 6), who undertook to determine the temperatures at which plant tissues freeze. His first concern was with the phenomena of supercooling and the determination of the ultimate freezing point, but in connection with this (5) he investigated the turning sweet of chilled potatoes.

Since then, Apelt (1) in Europe, 1907, has approached these questions by somewhat different methods, while in America Appleman (2) published his observations in 1912. In general, where their conclusions have not been in agreement, our own results have confirmed those of Müller-Thurgau. In none of these earlier publications, however, was critical attention focused upon the internal lesions or symptoms of frost necrosis and it is chiefly here that our own efforts have aimed to supplement those of previous workers.

While the details must be left for later consideration it will be helpful at the outset to summarize the conclusions upon which there is general agreement.

Plant tissues, in general, must be cooled to some degree below the freezing point of water before ice crystallization begins. With the potato it is the consensus of judgment that there is no killing of tissue or other permanent or injurious effect short of ice crystallization. Where tubers are held at temperatures near or slightly below the freezing point of water, but above the freezing point of the potato tissue, they turn sweet owing to the accumulation of sugar produced by the gradual starch conversion. It is commonly believed by potato handlers and has even been stated in literature by Norton (7, p. 70) that this is due to their having been slightly frozen. Müller-Thurgau (5, p. 753), and others since, particularly Apelt (1, pp. 12–27) and Appleman (2, p. 330), have disproved this. By storing potatoes for long periods as low as –1.66°C. (29°F.) Appleman (2, p. 333) determined that sugar accumulated most rapidly at 0°C. or below, and that freezing with potato tubers began between –2.2° and –3.3°C. (26° and 28°F.). Müller-Thurgau (5, p. 753) stored potatoes at temperatures ranging

from 0° to –3°C. for two weeks and found them still unfrozen after that period. Our own results as will appear later, confirm their conclusions that there is a considerable range possible in this critically low temperature at which tubers may turn sweet before they begin to freeze. Furthermore, none of these men has ever found potatoes to become sweet as a result of freezing consequent upon rapid cooling. Instead they determined the rate of sugar accumulation to be very slow even under most favorable temperatures. Our own experience is in accord with this in that we have regularly tasted tubers frozen experimentally without discovering evidence of increased sugar content in the potatoes which we have subjected to freezing temperatures enduring from 2 hours to 2 days. Hence, while sweetness indicates that tubers have been held for some time dangerously near their freezing point, it does not indicate that they have been frozen.

Müller-Thurgau (4, p. 147) showed that living plant tissues in general require supercooling to some degree below their true freezing point before ice crystallization begins. He found that the freezing point of the expressed sap of a potato tuber was –0.65°C. while the living potato tuber tissues in his experiments required supercooling to –3.2° to –6.5°C. before they began to freeze. Apelt's results with the potato, using a less reliable method we believe, are not in full accord with this, but our own trials confirm Müller-Thurgau's conclusions that supercooling is the normal course when potato tissues freeze. The earlier workers were led to define rather exact temperature limits for these phenomena with potato, generalizing, perhaps, from work upon a few tubers of uniform type, although they do not agree among themselves upon these limits. On the other hand, our work shows that there is considerable range in variation between individual tubers, even in the same lot of potatoes. The most interesting point and one of considerable practical importance in relation to symptomatology, is that there may also be a considerable range in susceptibility to frost necrosis between the different tissues in the same tuber. Here again Müller-Thurgau records the greater sensitiveness of the "cambial" as compared with parenchymatous tissues, and of the stem end as compared with the eye end of the tuber, but Apelt failed to confirm these differences. Our own results

not only show the correctness of Müller-Thurgau's general observations but enable us to go considerably farther than did he in defining such local differentiation. It is, indeed, because of these differences as to tissue susceptibility that potato tubers when subjected to the higher freezing temperatures may exhibit various types of internal symptoms.

Experimental Materials and Methods

Potato tubers which showed necrotic areas internally and which were known to have been subjected to freezing tem-

FIG. 1.—FROST NECROSIS PRODUCED EXPERIMENTALLY

A and A′ are longitudinal halves of a potato tuber. A was exposed to temperatures ranging from +10° to —5° C. for 24 hours and shows vascular discoloration of the net type of freezing injury. Notice more severe injury to stem-end (below). A′, control half, was not subjected to freezing temperatures.

peratures were found so frequently that, as already explained, it seemed advisable to determine experimentally the symptoms of freezing injury as compared with those of other maladies. The results of such work during the years 1915–1916 show conclusively that potato tubers when slightly frozen are often internally discolored while externally unharmed. Later, in 1918, when a freezing machine became available from which accurate temperature data could be obtained, a more critical study was

made of the temperatures at which this injury becomes apparent. Most of the temperature data herein tabulated were secured from these later experiments but they accord in general with those obtained in the earlier trials.

Earlier work, 1915–1916. In 1915 we obtained a quantity of potato tubers of the variety Rural New Yorker which had been grown, harvested, and stored under conditions as nearly uniform as practicable. In addition to these, potatoes were used in 1916 which were harvested at different stages of maturity so that data were obtained on the susceptibility of potatoes of different ages. At first each tuber used was cut in half longitudinally, one half kept for a control and the other frozen. In no case did the necrotic symptoms (fig. 1), which appeared so frequently in the frozen halves, develop in the controls. Potatoes which showed internal spotting of any kind were rejected for experimental work, and where potatoes were not cut in halves the stem end was cut off in advance to determine whether or not any internal spotting was present.

The tubers were either exposed out-of-doors or in a simple freezing chamber. In the out-of-door experiments great numbers of potatoes could be kept under like conditions, from 30 to 50 tubers often being used in a single experiment. This afforded a better opportunity for studying individual variation in susceptibility than was possible in the freezing chamber, where, at most, only 12 to 15 tubers could be tested at one time. In the out-of-door experiments a thermograph was used for recording temperatures; in the freezing chamber thermometer readings were made. The apparatus used in these experiments was of the simple ice cream freezer type of construction, easily understood from figure 2, which shows the insulating box surrounding the three cylindrical tin cans, each fitted with a tight cover and completely enclosing the one next inside. The tubers were held at the level of the mercury bulb of a long-stemmed thermometer, the scale of which was well above the cover of the freezing chamber so that it was not necessary to change its position to read the temperatures.

In setting up an experiment the ice and salt were first packed about the container, the potatoes next inserted in the inner chamber and the can covers and the thermometer then put in position. Using this method a half hour or more was necessary

for the temperature of the freezing chamber to drop to the desired degree below 0°C. Attempts were made to reduce materially this preliminary cooling period by packing the freez-

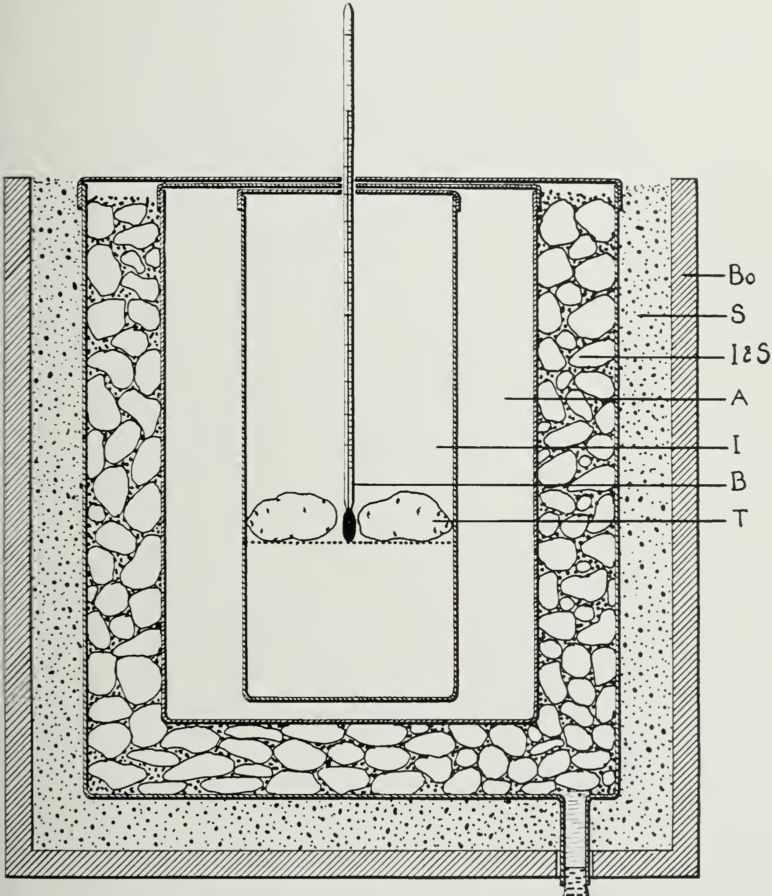

FIG. 2.—FREEZING APPARATUS USED IN 1915-1916

Diagram of freezing chamber in which the containers are all cylindrical tin cans fitted with tight covers, except the outermost, which is of wood. Tubers (T) are placed in inner chamber (I) supported by a wire gauze which is held at the level of the mercury bulb of the thermometer (B). This inner chamber is insulated by air space (A) and cooled by the freezing mixture of ice and salt (I and S). Sawdust (S) is packed between the box (Bo) and freezing mixture.

ing mixture about the chamber an hour before the insertion of the tubers that chamber and container air might be fully chilled in advance. It was found to make little difference, however, since the air disturbance consequent upon opening

the chamber and inserting the tubers was such that the preliminary period needed to bring the chamber to 0°C. was practically as long as by the first method. Müller-Thurgau used a freezing machine not unlike that described above and he re-

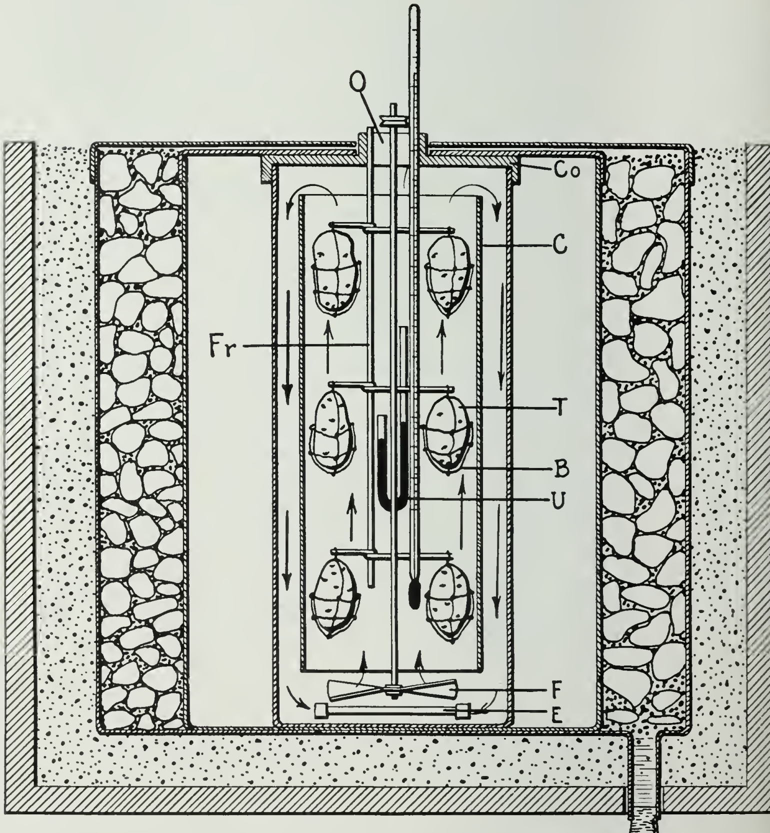

FIG. 3.—THE POTTER FREEZING APPARATUS

The general structure of this machine is like that used in the earlier work (fig. 1). The inner freezing chamber, however, has several new features. Heat is furnished by electric coil (E) which is regulated by electrical connections with the thermostat, the U-tube of which is represented by U. These electrical connections (not shown in diagram) were made through opening (O) in the heavy iron cover (Co) which also supports the frame (Fr) for the wire baskets (B). The arrows indicate the general direction of air currents which are produced by revolving fan (F). It is to be noted that the inner cylinder (C) is open at both ends, above and below, this permitting free air circulation.

cords constant temperatures throughout an experiment. Apparently he did not take into consideration the rate of fall nor

[1] For the use of this apparatus we are indebted to Geo. F. Potter, of he Department of Horticulture. Mr. Potter designed it primarily for study of the effects of freezing temperatures on the roots of nursery stock. He will publish the full details in relation to its construction and operation soon, but we are permitted through his courtesy to indicate the general features and unusual advantages of this apparatus.

the fluctuations which must have occurred where experiments were continued for several hours.

Later work, 1918. In our recent experiments (1918), we have used the Potter freezing apparatus[1] which has furnished more accurate data with ability to satisfactorily control the temperatures. The general construction of the freezing chamber (fig. 3) is similar to that described above but special devices are added for accurately controlling the rate and degree of cooling the freezing chamber. This is accomplished through the insertion of an electric heating coil with a regulating device such that the temperature can be made to fall at an exactly controlled rate and stopped and held constant at any desired point short of the extreme temperature procurable by the ice-salt mixture. Since this latter point is much below the temperatures with which we were concerned in our potato freezing trials the apparatus proved highly efficient and satisfactory. In most of these trials the apparatus was so adjusted as to drop the temperature in the experimental chamber to 0°C. at the end of the first half hour and to lower it 3½ degrees each hour thereafter until the desired minimum was reached.

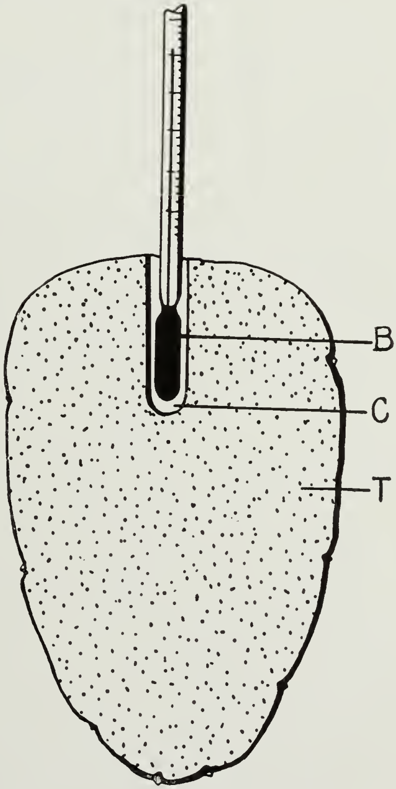

FIG. 4.—LONGITUDINAL SECTION OF TUBER AS USED IN SUPERCOOLING EXPERIMENTS

Thermometer bulb (B) is inserted in cavity (C) made in stem end of tuber (T).

For determining the internal temperatures of freezing potatoes. Müller-Thurgau's method was employed as described by him (1, p. 168). Two thermometers were used, one of which was suspended in the air of the freezing chamber, the other in a cavity made in the end of a tuber as shown in figure 4.

In order to preclude any undue pressure or the freezing of sap from the cut surface of the tuber upon the mercury bulb of the thermometer, the thermometer was so suspended that it did not press against the bottom of the pit and the cavity was made about twice as great in diameter as the thermometer and was carefully dried out with filter paper to rid it of free surface sap. No doubt the mercury bulb touched the walls of this cavity but the data (Table IX) indicate that the temperature readings were not influenced perceptibly by pressure or the freezing of water upon the bulb. While the temperatures obtained in this may not indicate the temperatures of the whole tuber, they do markedly differ from the air temperatures and give some indication of what may be taking place inside the tuber.

In the 1918 experiments carefully selected tubers were used chiefly of the Rural New Yorker variety. These had in all cases been harvested and stored without risk of freezing and sufficient numbers of untreated tubers were cut open to prove them to be generally free from internal lesions. This enabled us to proceed confidently in their use without previous cutting of each experimental tuber since this exposure of freshly cut tissue introduces a disturbing factor. The later trials were conducted during the latter part of the normal storage period, February–July. In some cases the tubers were kept previous to trial in the warm, dry laboratory long enough to secure partial wilting in order to compare normally turgid with wilted specimens. In the latter part of the period (March–July) Triumph potatoes were introduced into the trials. These had been previously stored at .temperatures approaching 0°C so that there had resulted a considerable sugar accumulation. In June and July recently dug, immature southern samples of Triumphs were available for comparison with this old stock. Some Early Ohios and Irish Cobblers were also tested at this time. In previous years trials had been made involving different varieties, degrees of turgidity, and stages of maturity. The details regarding these are given later in this article so that it will here suffice to state that in general neither variety, size, relative turgidity nor stage of development nor maturity of the tuber influenced in any marked degree the liability to frost necrosis or the type of resultant injury.

The Symptoms of Frost Necrosis in Potato Tubers

Effect of freezing upon the potato. A potato tuber that has been completely frozen will upon thawing be soft and watery and will quickly collapse or decay. If the tuber is cut open water drips freely from it and even before cutting the sap freed by freezing oozes through the skin so that the surface is soon wet. This soft, wet condition immediately indicates the trouble to one experienced in handling potatoes exposed to frost. Very often potatoes are thus frozen and collapse on one side only (Pl., fig. C), owing to one-sided contact with a frosty cellar wall if in storage or to a cold car floor if in transit, or it may occur through partial exposure at or near the surface of the ground before harvest. If such a frozen potato is cut across soon after thawing the cut surface of the interior flesh, although watery, is not at first discolored. Upon exposure to the air it will, however, very soon pass promptly through pink, red, and brown discolorations to a uniform inky blackness. This, according to Bartholomew (3, p. 631), is due to the oxidation of certain elements in the freed sap upon their contact with the air. Evidently the absence of discoloration before the tuber is cut is due to the fact that in the process of freezing and thawing the sap passes from the interior of the cells to the intercellular spaces thus driving out the free air and making its reabsorption almost impossible until the tuber is cut. It is often the case in nature that the exposure to freezing temperature stops short of the time or degree necessary to the uniform or complete freezing of the tubers. In this case few or none of them may show the softening or the wet surface characteristic of the frozen tuber yet, when they are cut open, various types and patterns of internal discoloration may be found. Since such frost necrosis may bear close resemblance to other types of internal discoloration of the potato tuber, and indeed necrotic lesions of different types may occur in the same lot of potatoes, we have undertaken to induce frost necrosis by experimental methods in order to determine the various forms of lesions.

Symptoms of frost necrosis as developed experimentally. As a rule, potatoes from the experimental freezing chamber which do not immediately show evidences of complete freezing, i. e.,

become soft and watery, will thereafter develop no external evidences of injury even though extensive internal necrosis has resulted. In exceptional cases, however, upon tubers having a clean, smooth, white skin, locally darkened areas may gradually appear where the interior discolored areas lie in the cortex close under the skin (fig. 7, B). This is not, however, a uniformly reliable symptom and even where detected requires confirmation through cutting of the tuber.

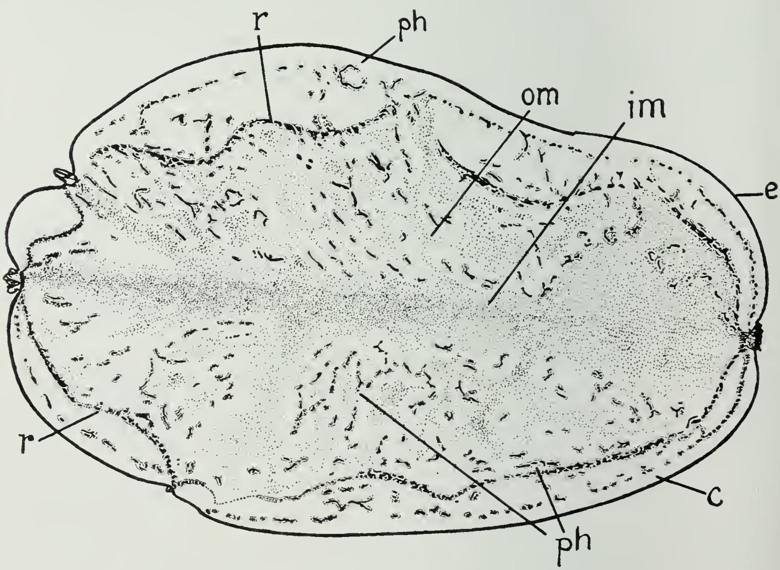

FIG. 5.—DIAGRAM OF LONGITUDINAL SECTION OF A POTATO TUBER

The heavier black portions represent vascular elements, the stippling indicates translucent tissue of high water content. The vascular ring (r) connects the stem end of the tuber at the right with the eyes scattered over the surface. The other gross structures are as follows: Corky epidermis (e), cortex (c) with scattered phloem elements (ph), outer medulla (om) with scattered phloem elements (ph), and inner medulla (im).

The internal lesions of frost necrosis appear as discolored areas in the flesh. These may not show marked discoloration in tubers cut immediately after their removal from the freezing chamber, but, as will be discussed later, color differentiation is completed after five or six hours. In many cases this discoloration is quite definitely limited to the vascular ring or follows the finer network of vascular elements which branch from this through the outer cortex or interior pith regions. Frequently where the injury is more severe or of longer stand-

ing the discolored lesions appear as blotches or diffused areas scattered less regularly through the flesh. Even in such cases critical examination shows that the discolorations are limited to well-defined areas. This can best be determined by examining a thin razor section of a necrotic tuber by transmitted light. In such sections the central core of pith and the vascular elements are highly transparent in contrast with the starch-filled parenchyma cells of the cortex and outer pith, and the darkened cells killed in the process of freezing are almost without exception those of the vascular elements and the cells bordering upon them.

As is shown in figure 5 the arrangement of the vascular system of a potato tuber is unlike that ordinarily met with in modified stems for in addition to the vascular ring there are throughout the cortex and pith—except in the inner core mentioned above—a network of small branching conductive elements largely composed of phloem elements, and when these vascular elements are all blackened we have a typical net necrosis (fig. 2, A and Pl., fig. D). This symptom, however, is less common in potatoes frozen in field, pits, etc., than are the blotches which appear in the cortex, vascular ring and outer pith, and which have as centers vascular elements (fig. 3). Müller-Thurgau (6, p. 455) noted this distribution of lesions and figured it in 1886. He says in regard to the tubers in which ice crystals have been formed, "These tubers showed externally in no way the appearance of frozen potatoes, but when they were cut, soft places were evident which, upon exposure to the air, turned red and later brown. As the observations showed, these dead tissue areas were the parts where the first crystal formation had occurred. These were never uniformly distributed throughout the potato but showed alike in over 100 trials of this kind a very constant relation in that they occur in the cambium-zone and immediately adjacent parts."

He adds, "In addition to the roundish dead spots in such potatoes one finds early-killed cells about the irregularly-running little bundles of vessels which are the places where the ice is formed very early and it is possible that along these paths the freezing process is distributed to new centers." Why these

tissues are more susceptible to low temperatures than others is a question for the plant physiologist to determine. Müller-Thurgau attempted to explain it upon the basis of water or carbohydrate content, but gives no conclusive results based upon experimental evidence.

Types of necrotic lesions. No two frosted potatoes show identical internal lesions but we have found it practicable and convenient to distinguish three types of necrosis which may be

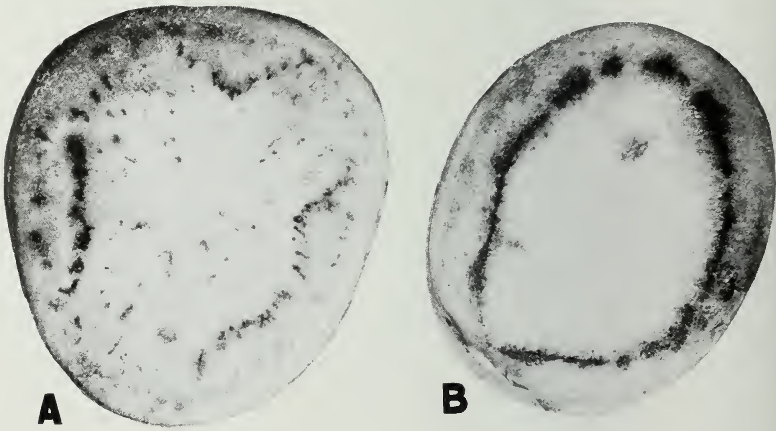

FIG. 6.—NET AND RING TYPES OF FROST NECROSIS EXPERIMENTALLY PRODUCED

Cross section of two tubers which had been exposed before cutting to a temperature of —8.5° C. for two hours. The symptoms are much more intense than those produced at higher temperatures (See fig. 1).

A—Intense net discolorations. Notice blackened vascular elements in both medulla and cortex.

B—Intense ring type somewhat complicated by blotch.

termed net, ring, and blotch. It is, of course, to be understood that any such grouping is somewhat arbitrary, that one type often merges into another, and that of each there are variations.

(1) In the net type there is more or less general blackening of the finer ramifications of the vascular elements extending as a network from the vascular ring internally toward the pith and to a less extent externally into the cortical region (fig. 6, A and Pl., fig. D).

(2) The ring type is characterized by a more pronounced blackening of the tissues in and adjacent to the vascular ring. It may be rather wide and diffuse (fig. 9, B) or narrow and

intensely blackened (fig. 6, B) and is often restricted to the stem end.

(3) The blotch constitutes a less well-defined type where the discoloration appears as small ovoidal or larger irregular patches ranging from an opaque grayish color to sooty black. These occur most commonly in the vascular ring and cortex although they may be located in the pith (fig. 7, A and B, and Pl., fig. A, B, E).

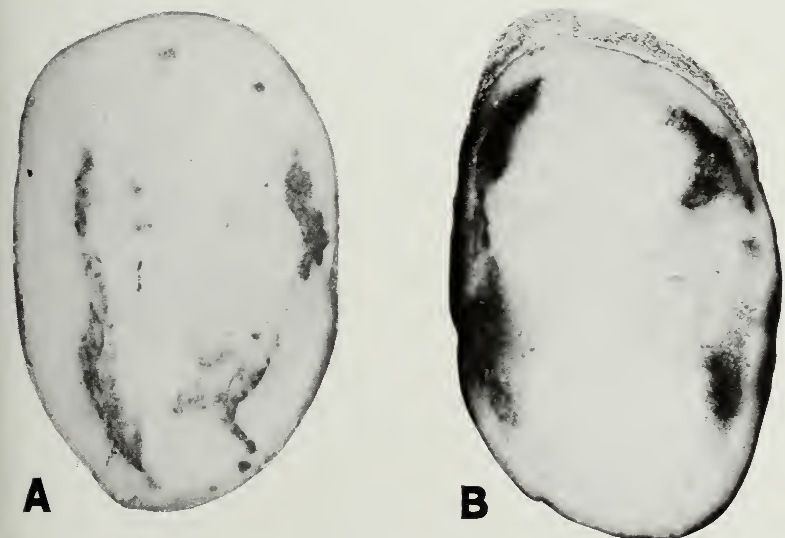

FIG. 7.—BLOTCH TYPE OF FROST NECROSIS

A—Longitudinal section of a tuber exposed to temperatures ranging from 0° to —4° C. for nine hours. Blotches more abundant in stem end.
B—Cross section of the stem end of a necrotic tuber. The intense blotches in the vascular and cortical regions were evidenced by dark areas on the exterior of the tuber.

When any considerable number of tubers are subjected to identical freezing conditions it will be found upon cutting them open that different types of frost necrosis may have resulted so that one cannot with exactness associate these different symptoms with definite temperature exposures. Numerous observations have, however, shown that some conditions of freezing give a preponderance of certain necrotic types. For example, with Rural New Yorker tubers held at –5°C. for two hours a high percentage of net necrosis resulted (Table 3), the symptoms becoming more intense with prolonged exposure. This

FIG. 8.—BLOTCH TYPE OF FROST NECROSIS FOUND IN STORAGE

A—Cross section of the stem end of a tuber frozen in storage.
B—Longi-section of the remainder of the same tuber. The lesions in this case are confined to a relatively small portion of the stem-end. The growth cracks in the interior flesh have no relation to freezing injury.

same symptom type occured in the Triumph variety as a result of an exposure of –8°C. for less than two hours and practically never at higher temperatures. The ring type is but slightly less common than the blotch in tubers of all varieties subjected for long periods to high freezing temperatures. Both occur commonly in potatoes which have been frozen in storage. Less definite blotch discolorations of the opaque type predominate in field frozen specimens (fig. 8), frequently being restricted to a sunburned side of the tuber. With Rural New Yorkers this blotching occurs with prolonged exposure, 12 hours or more, at –3°C. Tubers of the Early Ohio variety often in our trials showed a sooty ring, water-soaked and intensely black even when not subjected to extreme exposures. These observations, which are in the main deduced from a series of experiments with well-matured tubers during winter storage, are not presented as final evidence that varietal differences are constant factors. On the contrary, examination of hundreds of samples of several varieties of potatoes which were accidentally frozen do not indicate any such uniformity. They do show, however, that minor varietal differences appear where freezing conditions are accurately controlled.

While we have learned to expect internal darkening of the tissues as a regular symptom of severe frost necrosis, there are mild types in which this may not show much when the tubers are first cut open. In some such cases, even with tubers which had stood for a number of hours after removal from the freezing chamber, the only evidence of frost necrosis upon cutting them open was that the injured areas seemed drier and filled with air, and they showed a grayish-white tint when first exposed but within a short time turned red, then brown, meanwhile shrivelling somewhat. Although kept for a week or more none of these vascular or other injured tissues turned dark except on the cut surface. We have interpreted this as a mild type of local injury in which after certain cells were killed their freed sap was so absorbed by the adjacent tissues as to hasten their collapse and permit the entry of air into the intercellulars.

In addition to the symptoms above described potatoes may begin to freeze on the outside before any internal injury has taken place. This occurs most commonly where potatoes are

touching a freezing surface (Pl., fig. C) but also often happens in the Triumphs which have a very thin corky layer. Rarely it occurs in other varieties and without any apparent cause.

Symptoms of frost necrosis as found in storage. The occurrence of early autumn frosts in northern Wisconsin in both 1917 and 1918 caught potatoes so frequently that there have been numerous opportunities for observing the resultant effects upon such potatoes during winter storage. In general, these

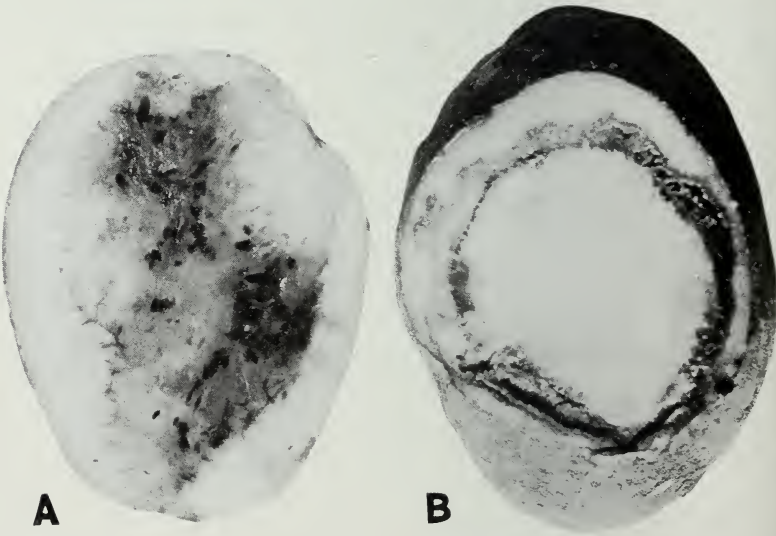

FIG. 9.—DRIED OUT NECROTIC LESIONS

Tubers found in storage in March which appeared perfectly sound externally. A—Net type of frost necrosis in which pitting has resulted from drying out. B—Ring type, very opaque discoloration, also pitted.

observations have shown that under good storage conditions and where only internal necrosis occurs the symptoms do not change much. As a result, tubers showing the milder degrees of internal frost necrosis may lie in the storage bin all winter practically indistinguishable from the normal tubers with which they are intermingled. It is true that if the internal lesions are very extensive such tubers will tend to wilt or shrivel worse than the normal ones and show internal pitting when cut (fig. 9). Also, Fusarium dry rot attacks them rather more frequently, probably following up the dead vascular areas from the stem end tissues. So far as can be judged from general

observations, such Fusarium invasion in its earlier stages merely intensifies the injuries, slowly increasing their area and giving the tissues a darker color, but not essentially changing their type. If this proceeds to the later stages of dry rot the distinguishing symptoms of frost necrosis are soon obliterated.

Black heart symptoms may also complicate those of frost necrosis particularly in storage. While it is probable that in many cases these symptoms may have resulted from other factors than those which condition frost necrosis there is some evidence that they may occur as a result of freezing.[1] In February, 1919, some tubers were found in Rhinelander, Wis., which showed both the net type of frost necrosis and black heart. They had been stored in a well-ventilated room held at temperatures constantly below 60°F., averaging nearer 40°F., and had been subjected to one sudden freezing temperature when a door had been left open on a very cold day.

Rate of discoloration of frozen tubers. Since the lesions of frost necrosis result directly from the oxidation of cells killed during the freezing process, they are not evident in tubers when they are first removed from the freezing chamber but appear only after such tubers have been exposed to warm air for several hours.

In order to determine the color changes which occur during the oxidation process and the time necessary for their completion, experimentally frozen tubers were thawed at different temperatures and slices cut from them at short intervals during several days. It was determined that the color cycle, like that described and pictured by Bartholomew (3, p. 631) for black heart, ranges through pinks, browns, and grays and seems to

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[1] The difficulty of learning exactly the causal factors concerned with internal discolorations is well illustrated by recent observations with two lots of seed potatoes. In one case the grower stored his potatoes temporarily in pits in the autumn and found some "wet" tubers indicative of freezing upon transferring later to the winter storage cellar. These were sorted out and the rest of the tubers, some of which were preserved for seed, kept well and began to sprout normally the following May. When cut open during the winter storage period frequent cases of frost necrotic discoloration were detected. Preparatory to planting the tubers were disinfected in May and then left in the open for several days to dry and start new sprouts, being covered with blankets. Upon cutting this seed stock it was found to show much black heart in addition to frost necrosis. The grower suspected frost as responsible for all his injury but E. T. Bartholomew, who examined this with us, diagnosed the black heart as resulting from heat consequent on exposure to the sun following disinfection. This was confirmed by similar exposure of another lot of seed tubers, known to be free of internal discolorations. Leaving these a few hours exposed to hot June sun was enough to induce a considerable amount of black heart. While this heat injury is less likely to occur at digging time it is nevertheless possible, especially with the early or southern crop.

develop simultaneously throughout the injured tissues. The time required for the ultimate dark color to be reached depends in part upon the air temperature; thus, at temperatures of 10° to 15°C. from ten to twelve hours were required, while at 25° to 30°C. only five or six hours were necessary. There was no evidence that the rate of thawing influenced the degree of injury nor that tissues which had received severe freezing injuries blackened more rapidly than did those with lesser injuries.

FROST NECROSIS SYMPTOMS CONTRASTED WITH THOSE OF OTHER TUBER MALADIES[1]

In freshly frozen tubers frost necrosis may, in general, be easily distinguished from other potato tuber diseases by the distribution and color of the lesions. Sometimes it may happen that the lesions shown by a single tuber may be so little characteristic as to leave one in doubt, but if several tubers are available, confident judgment is usually possible. If, however, such tubers have lain for some time following the injury, secondary storage rots may set in and complicate matters. Since the same forms of storage rot may follow secondarily after various other initial injuries the only recourse in such cases is to seek for as clear evidence as is obtainable concerning the character of the initial injuries and base final judgment upon this.[2] It is also helpful in diagnosis of injuries in stored potatoes to know the region from which the tubers came since, to

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[1] Since detailed descriptions of the above-mentioned tuber diseases occur in current phytopathological literature no attempt is made here at their full characterization. Should this be desired in any case the following citations will furnish illustrated accounts: Late blight dry rot, Jones, L. R., Giddings, N. J., and Lutman, B. F., *Investigations of the potato fungus Phytophthora infestans.* U. S. D. A., Bur. Pl. Ind. Bul. 245, pl. 2, 1912; Fusarium dry rot, Orton, C. R., *Potato diseases.* Penn. State Agr. Exp. Sta. Bul. 140, p. 26, fig. 13, 1916; Bacterial brown rot, Smith, E. F., *Bacteria in relation to plant disease,* v. 3, p. 174, pl. 23, 1914; Net necrosis, Orton, W. A., *Potato wilt, leaf-roll and related diseases.* U. S. D. A., Bur. Pl. Ind. Bul. 64 (professional paper). p. 8–9, pl. 2, fig. 2, 1914; Black heart, Bartholomew, E. T., *Black heart of potatoes.* Phytopathology, v. 3, pp. 180–182, pl. 19, 1913; Internal brown spot, Horne, A. S., *The symptoms of internal disease and sprain (streak-disease) in potato.* Jour. Agr. Sci., v. 3, pp. 322–333, pl. 19, 1910.

[2] Critical attention has been given to the symptoms of frost necrosis as it appears in the city markets, especially in the markets of Chicago where northern grown potatoes are handled, by Geo. K. K. Link and M. W. Gardner. Their observations were continued over a period of sufficient duration to afford an opportunity to study both initial frost injuries and those complicated by storage rots at different seasons. The writers have had access to their results in an unpublished manuscript which will be issued later by the United States Department of Agriculture as a handbook of diseases of vegetables occurring under market, storage, and transit conditions, prepared under the direction of W. A. Orton of the Bureau of Plant Industry and W. M. Scott of the Bureau of Markets.

one acquainted with conditions, this may give important suggestions as to the probable initial causes. The commonest of such types of tuber injury initiated by factors other than freezing are as follows:

1. **Dry rot.** Of these, late blight rot caused by *Phytophthora infestans* is distinguished from frost necrosis by the fact that the initial lesions are strictly superficial, the discoloration rarely proceeding deeper than the cambial region and with no tendency to follow the vascular distribution as does frost necrosis.

The common types of Fusarium dry rot, of which examples occur in practically every lot of storage potatoes, as a rule show conspicuous external lesions and when cut open the uninvaded flesh is uniformly bright and normal in appearance whereas freezing injuries show as persistent discolorations.

2. **Wet rot, soft rot.** Following severe freezing injuries to potatoes all fully frozen tissues collapse immediately upon thawing. Often only part of a tuber is so involved, in which case the remaining flesh if cut open may show the net or blotch lesions characteristic of frost necrosis. As a rule, however, bacterial wet rot immediately follows as a secondary trouble and proceeds to the destruction of the entire tuber. In case of severe attacks by the bacterial blackleg disease the tubers may show a soft rot either while in the soil or soon after harvest. In most cases, however, such rapid wet rot is a secondary development following late blight or some other initial injury to the tuber, especially in heavy wet soils.

3. **Ring necrosis.** Stem-end bundle blackening occurs in some degree in many potato tubers, showing as a darkening when the stem end is cut across. This may be very shallow (perhaps one-eighth inch or less) in which case it is considered non-parasitic in origin, or it may extend well through the length of the tuber, in which case it is usually attributed to Fusarium invasion. The former type should lead to no confusion with frost necrosis but the latter may. In general, it may be differentiated by its being more strictly limited to the vascular elements of the cambial ring without the attendant net necrosis or blotch lesions of frost necrosis.

4. **Brown rot.** This name is applied to the bacterial disease, caused by *Bacillus solanacearum*, which may cause a wet, slimy

rot of the vascular ring. It is, however, readily distinguishable, as a rule, by the showing of a typical grayish bacterial exudate from the vascular elements in the earlier stages, by the wetter condition of the tuber in the later stages, and by its restriction to southern stock, whereas frost necrosis is to be expected in northern stock.

5. Net necrosis. This name has been applied to a condition where the vascular elements brown more or less throughout the flesh of the tuber even during the developmental stage, i. e., before digging. This is considered non-parasitic and is inheritable from generation to generation. It seems impossible by appearance alone to distinguish confidently between this inheritable net necrosis and the net type of frost necrosis. In practice, however, where one is dealing with any considerable number of examples of necrotic tubers, there will probably be little difficulty in correct diagnosis. In the case of frost necrosis only a part of such tubers should show lesions of the net necrosis type, others showing ring and blotch discolorations. Probably in most cases some significant evidence may be obtainable also as to the history of the sample, including liability to exposure to freezing temperatures.

6. Black heart. The typical black heart lesions, resulting from high temperature storage or asphyxiation through confinement with insufficient free oxygen, consist of clearly delimited internal discolorations. In certain cases of frost necrosis as already cited (see p. 19) J. P. Bennett has found black heart symptoms where the history of the tubers seemed to preclude the above types of asphyxiation. In any case, this is not likely to be common or seriously confusing.

7. Internal brown spot. This non-parasitic and non-infectious malady is characterized by definite brown spotting of the interior flesh of the tuber. It is readily distinguishable by its brown color from the internal grayish or purplish black frost blotch necrosis. The distinction is made surer by the absence in this brown spot malady of any tendency toward vascular discoloration of the ring or net types so commonly associated with frost necrosis. According to Horne's description internal brown spot lesions may be delimited by cork cells in which case microscopical examination should assure their differentiation from frost necrosis.

THE AMOUNT AND TYPES OF FROST NECROSIS WHICH OCCUR AT DIFFERENT TEMPERATURES

Because later experiments (pp. 35–36) show that the rate of fall of temperature is one of the factors which seem to influence the amount of injury tubers sustain when chilled, the following data are compiled entirely from the 1918 experiments in which the Potter freezing machine was used. They show a certain uniformity in the types of injury which occur at the same temperatures, but also indicate the striking individual resistance of tubers in many cases. Unless otherwise indicated, tubers of the variety Rural New Yorker were used in these tests, and the air temperature was dropped at the rate of 3½°C. per hour after the zero point was reached. The percentage of injury as shown in these tables is not very conclusive since only 10 or 15 tubers at most were exposed at one time. However, they correspond in general with the data obtained in the earlier experiments where larger numbers of potatoes were exposed under uniform conditions out-of-doors and where individual resistance also showed strikingly.

Injury above –3.2°C. Müller-Thurgau (4, p. 147) held that the critical temperature at which potatoes regularly began to freeze was –3.2°C. and Appleman (2, p. 333) stated that this process began at temperatures ranging from –2.2° to –3.3°C. In our experiments, therefore, the attempt was made to reconcile their results. In numerous experiments tubers were held at –2°C. for hours (in some cases for 48 hours) and no injury ever resulted. Similarly, temperatures ranging from –2.0° to –2.5°C. were tested and found to be too high to produce injury. Between –2.5° and –3.0°C., however, although frost necrosis did not always occur, it did in perhaps 50 to 75 per cent of the experiments, depending upon the length of the exposure and the individual susceptibility of the tubers under trial. The following table gives data as to amounts and predominating types of injury from several of the experiments in which temperatures of from –2.5° to –3.2°C. were used.

TYPES OF FROST NECROSIS IN MARKET POTATOES

A.—STEM END INJURY

Cross section of the stem end showing irregular blotches. The whitish areas together with the wilted appearance of the surface of the tuber indicate drying out which often follows freezing injury in storage. The general distribution of lesions in such tubers is well represented in figure E, a longitudinal section of another tuber in which injury is restricted to the stem end.

B.—GENERAL DISCOLORATION OF STEM END TISSUES

Cross section of the stem end in which blotches are accompanied by a general discoloration. Whitish areas in the cortex again indicate drying out.

C.—RING DISCOLORATION AND ONE-SIDED FREEZING INJURY

Cross section of a tuber one side (left) of which was evidently in contact with a freezing surface. The double ring of darkened vascular elements may have resulted from the same exposure as did the one-sided injury or from another exposure to freezing temperatures.

D.—NET TYPE OF FROST NECROSIS

Section of a tuber which shows a very uniform darkening or browning of the vascular elements throughout the tuber. This symptom is very common in turgid tubers which have been exposed to temperatures approaching —5°C. Notice how sharply the injury is limited to the vascular elements.

E.—STEM END INJURY OF THE BLOTCH TYPE

Longitudinal section showing discoloration and drying out of the outer tuber tissues. Note that the injury is confined to the upper portion of this tuber, which is the stem end. See also figures A and B.

Reproduced from hand-colored photographs made under the direction of G. K. K. Link and M. W. Gardner of the Bureau of Plant Industry, U. S. Department of Agriculture.


A
B
C
D
E

Table I—Types and Amounts of Injury at —2.5° to —3.2°C. (27.5° to 26.2°F.)

Exp. No.	Exposure		Injury	
	Temperature °C.	Period	Frost necrosis	Frozen solid
1	-2.5°	6 hrs.	none	none
2	-2.5°	12 hrs.	blotch (faint), 20%	"
3	-2.8°	12 hrs.	" " , 15%	"
4	-2.5° to -3.0°	18 hrs.	" (sooty), 30%	" [1]
5	-2.6° to -3.2°	18 hrs.	" and ring, 60%	"
6	-3.0° to -3.8°	18 hrs.	" " " , 80%	10%
7	-2.8° to -3.2°	24 hrs.	" , 100%	80%

[1] In experiment No. 4 two tubers which had been peeled were included. These were frozen solid and the unpeeled were not. See further data bearing on this, Table III. Exp. 8, Table IV, Exp. 2, and later discussion of this point.

From Table I it appears that long exposures to critical temperatures are conducive to the production of the blotch type of injury, and that they ultimately result in the tubers freezing solid. The fact that this blotch type of discoloration is found commonly in field frozen specimens and that it occurs so regularly from prolonged exposure at these high temperatures is significant. Occasionally, however, the ring type is produced at these temperatures.

Injury at –3° to –4.5°C. The temperatures below –3°C. were employed in further experiments to determine the time during which such temperatures must be maintained in order to produce frost necrosis and also to furnish material for studying symptoms of tubers frozen at these lower temperatures. In storage and transportation tubers are often accidentally subjected to dangerously low temperatures for short periods. Table II gives the result of several experiments in which these temperatures were employed.

TABLE II—TYPES AND AMOUNTS OF INJURY at —3.2° to —4.4°C. (26.2° to 24°F.)

Exp. No.	Exposure		Injury	
	Temperature °C.	Period	Frost necrosis	Frozen solid
1	—3.2 to —3.7	5 hours...............	Blotch, 10%...............	None
2	—3.2 to —4.0	5 hours...............	Blotch and ring, 20%	None
3	—3.6 to —3.9	3 hours...............	None	None
4	—3.7 to —3.9	2 hours, 30 min.......	None	None
5	—3.6 to —4.2	5 hours...............	Blotch and ring, 50%	None
6	—3.5 to —4.2	12 hours..............	None	100%
7	—4.0 to —4.3	3 hours...............	Net and ring, 60%	None
8	—4.2 to —4.4	2 hours, 30 min	Net and ring, 50%........	None

Injury at –5° to –5.6° and at –6° to –8°C. The results of both the 1916 and 1918 experiments show that the highest percentage of net necrotic discoloration occurs after short exposures to temperatures of –5° to –5.6°C. These are not exclusive of other types but they predominate.

TABLE III—TYPES AND AMOUNT OF INJURY AT —5° TO —5.6°C. (23° TO 21.9°F.)

Exp. No.	Exposure		Injury	
	Temp. °C.	Period	Frost necrosis	Frozen solid
1	—5	1 hr., 30 min...........	blotch and net, 30%......	none
2	—5	1 ", 50 "	ring and net, 100%.......	"
3	—5	2 "	blotch and net, 50%......	"
4	—5	3 "	blotch, 70%..............	30%
5	—5.5	1 ", 30 min...........	ring and net, 20%........	none
6	—5.4	2 "	" " ", 50%........	"
7	—5.5	2 "	blotch and net, 60%......	"
8	—5.6	1 "	ring and net, 60%	2 peeled

TABLE IV—TYPES AND AMOUNT OF INJURY AT —6° TO —8°C. (21.2° TO 17.6°F.)

Exp. No.	Exposure		Injury	
	Temp. °C.	Period	Frost necrosis	Frozen solid
1	—6.0	1 hr.	net, 80%	none
2	—6.2	30 min.	" and ring, 20%	(2 peeled)
3	—6.5	45 "	" " blotch, 60%	none
4	—6.8	30 "	" " ring, 40%	"
5	—7.0	1 hr.	" " blotch, 70%	"
6	—7.4	45 min.	" " " , 100%	"
7	—7.8	2 hrs.		100%
8	—8.0	1 "	net and blotch, 100%	0

The net type seems almost as prevalent at these lower temperatures (–6° to –8°C.) as at the next higher (–5° to –6°C.) but in each case where it is recorded as being present the blotch predominated. In experiment No. 8 the net type occurred in Triumph potatoes while the blotch refers to the condition in the Rurals.

Not only do these experiments show that net necrosis develops very commonly as a result of short exposures at rather extreme temperatures, but it has been found as the predominating type in cases of freezing injury to storage potatoes where the temperature has been known to drop suddenly. On the other hand, it has rarely been observed in cases of field injury before digging.

Injury at –10.5° to –11.7°C. Potatoes freeze solid at temperatures below –10°C. if they are exposed for any considerable time. Internal frost necrosis develops promptly in all such tubers with the blotch type predominating over the net. It is also of interest to note that at these extreme temperatures freezing begins more often at the surface and proceeds inward. Thus, in experiments 3, 4, and 5 of Table V the tubers reported as frozen solid were not entirely frozen but had begun thus to freeze from the surface, and in some the peripheral half-inch was thus killed but the interior was intact.

TABLE V—TYPES AND AMOUNT OF INJURY AT —10.5° TO —11.7°C. (13.1° TO 10.9°F.)

Exp. No.	Exposure		Injury	
	Temp. °C.	Period	Frost necrosis	Frozen solid
1	-10.5	45 minutes	blotch and net, 70%	none
2	-11.0	30 minutes	" " ", 70%	30%
3	-11.2	1 hour	blotch, 40%	60%
4	-11.7	45 minutes	" , 40%	60%
5	-11.7	1 hour	" , 10%	90%

RELATION OF TUBER CONDITION TO SUSCEPTIBILITY TO FREEZING

Throughout the course of these investigations individual susceptibility of tubers to freezing injury appeared constantly in field and storage as well as in experimentally frozen specimens, and it seemed probable that it might be explained by some internal condition of the tuber which could be produced experimentally if the external factors were controlled. Consequently, potatoes at different stages of growth which had been subjected to varying storage conditions were exposed to similar freezing temperatures and the results compared critically.

Relative resistance of mature and immature tubers. During the season potatoes of different stages of maturity were tested for resistance. Three plantings of the Rural New Yorkers were made on June 1, July 13, and August 10, respectively. All were dug on October 3, at which time the tubers from the first planting were mature, those from the second about half-grown, while those from the third measured from one-half to two-thirds of an inch in diameter. Soon after harvest, when these tubers were still turgid and unmodified by storage, trials were made in which several tubers from each of these plantings were exposed to the same freezing temperatures but no consistent difference in susceptibility appeared. To be sure, in some trials a larger number of mature than immature tubers remained normal, but in others the immature tubers seemed more resistant to freezing temperatures. As is common with turgid Rurals the net symptoms predominated in all of these tubers.

Figure 10 shows three of these potatoes, one from each planting, which were exposed together to –6.5°C. for about two hours.

Influence of relative turgidity of tubers. It is a natural supposition that the relative turgidity of the tuber tissues may influence their susceptibility to freezing injury. In some of the earlier trials partly wilted tubers were exposed along with turgid

FIG. 10.—INFLUENCE OF MATURITY UPON SUSCEPTIBILITY TO FROST INJURY

Sections of three tubers of different stages of maturity which were exposed together to a temperature of —6.5° C. for two hours. All were harvested on October 10; A from seed planted June 1, B from seed planted July 13, and C from seed planted August 10.

ones, and no consistent differences developed. Such comparisons have been made at various times during three seasons with like results. Owing to the individual variations between tubers it is difficult to make as convincing comparisons as might be desired, and it is impracticable to use a divided tuber for such experimental purposes because of the possible disturbing effect of cut surfaces upon supercooling.

In an effort to establish moisture conditions which were as nearly uniform as possible, in some later experiments turgid

Rurals were carefully paired off as to size and weight, the pairs numbered as 1 and 1′, 2 and 2′, etc. Numbers 1, 2, 3, etc., were placed in a damp chamber and 1′, 2′, 3′, etc., in a desiccator and both stored at a temperature of 10°C. Several pairs of tubers, e. g., 1 and 1′, 2 and 2′, etc., were removed and exposed to freezing temperatures each week for a period of two months and although the tubers used may have gained slightly or lost considerably in weight during storage their susceptibility to freezing was not consistently altered.

Tables VI and VII show the results of two experiments which give an idea of the distribution of injury in the two lots of potatoes.

TABLE VI—SYMPTOMS OF FROST NECROSIS AS SHOWN IN PAIRS OF TUBERS WHICH WERE STORED UNDER DIFFERENT MOISTURE CONDITIONS FOR 6 WEEKS AND THEN EXPOSED TOGETHER TO —4° TO —7° C. (24.8° TO 19.4° F.) FOR 2 HOURS

TUBER WEIGHTS IN GRAMS			PER CENT GAIN (+) OR LOSS (–)		FROST INJURY	
Original[1]	After 6 weeks					
	Damp chamber	Desiccator	Damp chamber	Desiccator	Damp chamber	Desiccator
31	34	29	+9	—16	net (faint).......	blotch (sooty)
55	55	48	0	—13	normal	ring "
34	34	29	0	—15	ring.............	" "
50	50	44	0	—12	"	normal
51	51	48	0	—6	"	"

[1] As indicated above each one of a pair of experimental tubers had the same original weight.

A comparison of these results shows that loss of turgidity does not consistently alter susceptibility. For example, the desiccated tuber of the second pair lost 13 per cent of its original weight (55 grams) and was injured upon exposure to freezing temperatures while its turgid mate remained normal but in the fourth and fifth pairs the opposite condition obtains. There the desiccated tuber of the fourth pair lost 12 per cent of its original weight (50 grams), that of the fifth pair 6 per cent of its original weight (51 grams), and yet both

apparently gained in resistance to freezing. Results of the same type appear in Table VII.

TABLE VII—SYMPTOMS OF FROST NECROSIS AS SHOWN IN PAIRS OF TUBERS WHICH WERE STORED UNDER DIFFERENT MOISTURE CONDITIONS FOR 6 WEEKS AND THEN EXPOSED TO —2.5° TO —7.0°C. (27.5° TO 19.4° F.) FOR 2 HOURS

Tuber weights, grams			Per cent. gain (+) or loss (—)		Frost injury	
Original	After 6 weeks: Damp chamber	After 6 weeks: Desiccator	Damp chamber	Desiccator	Damp chamber	Desiccator
23	23	21	0	—9	normal.........	ring (faint)
43	45	41	+2	—2	ring (opaque)..	net "
28	28	19	0	—32	" "	black heart
40	40	38	0	—5	" (faint)....	net (faint)
61	61	56	0	—8	normal.........	" "

Here the desiccated tubers of the first and fifth pairs seem less resistant and in the other cases the symptoms differ only slightly in the corresponding pairs. However, where the tuber was very much wilted, as was the desiccated one of the third pair, which lost 32 per cent of its water content, intense symptoms were produced which resemble black heart. This is an extreme form but it occurs not uncommonly, and it is indicative cf the increase of sootiness of necrotic symptoms with decrease of water.

Relation of sugar content. Müller-Thurgau (6, p. 493) has shown that the relative sugar content in the tuber may influence its freezing point. For example, by preliminary storing at low temperatures he raised the sugar content from 0.53 per cent to 2.21 per cent. His trials then showed that the true freezing point with these tubers was lowered from –1.0°C. for those of the normal sugar content, to –1.5°C. for those of the excessive sugar content. It is to be noted, however, that in his trials he secured extremes of variation far beyond those which are ordinarily met with in normal potato tubers and even so the influence upon the freezing point was not proportionately great. This factor may, however, be influential in determining the relative injury to the different tissue elements in the tuber.

Influence of wounds and bruises upon susceptibility. The presence or absence of a film of moisture on the exposed surface of a wounded or bruised tuber seems to determine the influence of such wounds and bruises upon susceptibility to freezing injury. When wounds or bruises are corked or healed over as in the case of common scab, dry rot, or mechanical injuries, they have no important influence upon the susceptibility of the tubers. Even freshly cut surfaces often seem not to cause freezing to take place at higher temperatures as Müller-Thurgau (4, p. 172) predicted. In his experiments with freshly peeled tubers he found that supercooling was prevented by the presence of the surface film of exuded sap on such tubers. He explained this as being due to the fact that this free sap began to crystallize at the freezing point of sap (about –1.0°C.) and that when the sap throughout the tuber was chilled to this degree the presence of crystals on the outside caused the freezing process to extend from the outside inward, without the usual supercooling phenomenon. In our experiments tubers were freshly cut in different ways, some were peeled and some split in half longitudinally, and from others slices were cut, most often from the stem end. It was found that peeled potatoes usually froze solid at temperatures which produced only minor injuries, if any, in sound tubers. In a few cases, however, typical necrotic symptoms appeared in these peeled tubers just as in the case of tubers with surfaces only partially exposed. In some cases freezing started on these cut surfaces and progressed inward for two or three millimeters while the usual necrotic symptoms appeared in the deeper-lying tuber tissues.

Relative susceptibility of sprout and tuber tissues. Sprouts have in our experiments always proved more resistant to freezing injury than the tissues of the tuber from which they arise. As a result, if a sprouted tuber is exposed to freezing temperatures the parent tuber may show considerable internal necrosis and have its sprouts unaffected (fig. 11). Since this has an important bearing upon the relation of frost necrosis to the value of potato seed stock, numerous trial plantings were made, some in sand in the greenhouse bench and some in the field soil. In certain of these experiments, in order to make closer comparisons, the trial tubers were cut in halves, one half being

FIG. 11.—EFFECT OF FROST ON VIABILITY OF TUBERS

A and B (Upper)—Sections of two tubers which were stored at 25° C. for three months, chilled at —5° C. for two hours, then returned to the 25° C. temperature.

C and D (Lower)—Control tubers held constantly at 25° C.

Sprouts had developed on all tubers when A and B were frozen. Freezing produced necrotic symptoms in A and B without apparent injury to the sprouts which, however, continued to grow much less vigorously than did those of the control tubers, as is shown in this photograph taken three months after A and B were chilled. The photograph also indicates the lack of storage rots and drying out in necrotic tubers, even where stored at such a relatively high temperature.

held as a control, the other chilled after the surface was well dried off. In practically all cases such exposed tubers retained viability even where there was internal necrosis but the sprouts started more slowly, and where the frost necrosis was very extensive the parent tuber rotted before the sprout developed independent roots. As a result, planting frost-necrotic tubers in the field yielded only about 50 per cent of a stand. Those plants which survived, although they started more slowly, made rapid gains later and were ultimately as vigorous and productive as the normal controls. The tubers thus secured from this frost-necrotic seed were in turn all examined for any traces of vascular necrosis, and found to be free. While this was to be expected, it is worthy of note as again emphasizing the distinction between net necrosis induced by freezing injury and the hereditary net necrosis from which the symptoms may sometimes be indistinguishable.

While, therefore, in general, it is inadvisable to plant tubers showing any large amount of frost necrosis, nevertheless slightly necrotic tubers may safely be used if one cuts them and rejects pieces which show lesions extensive enough to predispose to rot.[1]

SUPERCOOLING AND ICE CRYSTALLIZATION ASSOCIATED WITH FROST NECROSIS

No attempt has been made in connection with these studies to follow the microscopic phenomena associated with the changes in the potato, but it has been the conclusion of previous investigators that the formation of ice crystals in the sap is antecedent to the death of such plant tissues. So far as our evidence bears upon the matter, it is in accord with this idea. In most cases where frost necrosis resulted it was, indeed, possible to detect ice crystals in the tissues either by their macroscopic appearance if the tubers were immediately cut open, or by holding the suspected tuber close to one's ear and pressing

[1] Supplementing Müller-Thurgau's 1882 work (5) Wollny (8) attempted to determine the influence of prolonged cold storage upon the viability of tubers. He took normal tubers, divided them into longitudinal halves and stored one set of halves in a cold chamber at 0°C. and the controls at 10° C. After 35 days he planted each set separately and recorded growth throughout the season. The aerial vegetative parts were quite uniform from both kinds of tubers but at harvest time the hills from seed tubers which had been stored at 10° C. contained more and larger tubers than did those from the parent seed tubers which had been stored at 0° C.

sharply between thumb and finger, when the presence of ice crystals is revealed by a faint crunching sound. This is, however, but a crude test and its unreliability was shown by the fact that frost necrosis appeared in some cases where ice crystals were not so detected. Still more significant is the fact that in other cases ice crystals were heard when no evident injury resulted. So far as any conclusion was justified, therefore, it is that frost necrosis does not necessarily result from a slight amount of ice crystallization but that this must proceed to a certain advanced stage to produce death of the associated tissues.

It is a matter of common experience concerning the effect of freezing upon plant tissues that there are wide variations in susceptibility and various theories have been developed to account for this. Since our experiments give no new evidence bearing on these we will simply record the facts without attempting to relate them to such theories.
attempting to relate them to such theories.

Another interesting phenomenon having relation to ice crystallization is that known as supercooling. On this some evidence was secured. It is a familiar fact that any liquid must be cooled to some temperature below its freezing point before crystallization begins. This range of temperature below the freezing point is supercooling. Following supercooling there is a sharp temporary rise of temperature to the higher degree, this latter constituting the true freezing point of the solution (fig. 12). Since potato sap carries considerable matter in solution its freezing point is lower than that of pure water. Müller-Thurgau determined it to be about –1.0°C. but in our experiments it often more nearly approximated –2.0°C. than –1.0°C. and varied widely with individual tubers (Table IX).

Müller-Thurgau found further that where he made comparative determinations of the supercooling points of living plant tissues and of the expressed sap, the living tissues had a lower supercooling point than did the expressed sap. He also found that when the potato was frozen, then thawed, and frozen again, the extreme supercooling was not required for the second freezing. This lowering of the supercooling point in living tissues he attributed to the resistance of active protoplasm.

Relation of time element to supercooling. Müller-Thurgau held that the supercooling point varied directly with the air temperature to which the tuber was exposed; i. e., was depressed with the fall of air temperature. He justifies this conclusion by such data as are given in Table VIII.

TABLE VIII.—MÜLLER-THURGAU'S RESULTS SHOWING RELATION OF SUPERCOOLING POINT TO AIR TEMPERATURES

Exp. No.	Exposure		Potato Temperatures	
	Temperature °C.	Time	Supercooling point °C.	Freezing point °C.
1	– 4.5	2 hours	–3.2	–0.8
2	– 5.0	not given	–3.5	–1.2
3	– 7.2	" "	–4.1	–1.4
4	–11.0	4 hours	–5.7	–1.0
5	– 9 to –12	5 "	–6.1	–0.98

From our experience it requires some further explanation than is afforded by Müller-Thurgau's figures to understand why freezing should have occurred at the end of 2 hours at –4.5°C. and at the end of 4 or 5 hours at the extremely low temperatures of experiments 4 and 5, Table VIII. Müller-Thurgau, in his experiments, already explained, had no way of regulating the rate of fall of the air temperature in his freezing chamber. Fortunately, with the Potter freezing apparatus we were able to do this. We therefore undertook to repeat Müller-Thurgau's experiment controlling this time factor. The results, as shown in Table IX, indicate that the rate of fall of the air temperature influences the supercooling point.

TABLE IX—RELATION OF SUPERCOOLING TO RATE OF FALL OF FREEZING TEMPERATURES

Exp. No.	Variety	Air Temperature		Potato Temperature		
		Max. temp. °C.	Time to drop from o° to max. temp.	Super-cooling point °C.	Time to super-cool	Freezing point °C.
1	Rural........	—5.5	95 min........	—4.0	105 min.....	—1.25
2	"	—5.0	90 "	—4.95	174 "	—1.3
3	"	—10.5	80 "	—4.2	73 "	—1.8
4	"	—11.0	40 "	—3.1	49 "	—1.7
5	Irish Cobbler	—5.6	20 "	—3.5	100 "	—1.7
6	" "	—6.0	60 "	—5.5	125 "	—1.7
7	" "	—11.0	55 "	—3.2	58 "	—2.3
8	Early Ohio...	—4.4	120 "	—4.15	112 "	—1.9
9	" " ...	—8.0	40 "	—2.2	75 "	—1.6
10	" " ...	—11.0	45 "	—2.8	55 "	—1.5

From these data it seems evident that the supercooling point does not vary simply with the air temperature but that it is influenced by other factors, including the rate of fall of the temperature. Comparing tubers of the same variety, experiments 3 and 4 show that in 3 a slow drop to –10.5C. gave a lower supercooling point (–4.2°C.) than did a rapid drop in 4 to practically the same point. With another variety, in experiment 6, a slower drop to –6°C. gave a lower supercooling point (–5.5°C.) than did the rapid drop to –11°C. in experiment 7, (supercooling point –3.2°C.). It will be noticed that in general the supercooling points recorded in our trials (Table IX) represent about the same range as Müller-Thurgau's (Table VIII). These are also in accord with our general experience; viz., that potatoes do not begin freezing until exposed to –3°C. or lower. It will be noted, however, that in two cases, experiments 9 and 10, the supercooling point was reached above –3°C. These are to be regarded as exceptional cases requiring explanation. In the first place, in this method (see fig. 4) mutilated tubers are used and where freshly cut surfaces are exposed, even with precautions to dry them, the supercooling point may be raised. In the second place, the supercooling point may be influenced by such external factors as mechanical disturbance, as was indicated in some of our experiments.

The ultimate freezing point. The ultimate freezing temperatures as shown in Table IX are in general somewhat lower than Müller-Thurgau's, Table VIII. In both cases it will be noted that there is a considerable variation. It will be evident that the method employed can give only approximate results at the best, and also that this varies with individual tubers.

Relative temperatures of air and potato. Tables X and XI show in detail the comparative temperatures of air and the interior of the potato tuber and the supercooling range as fol-

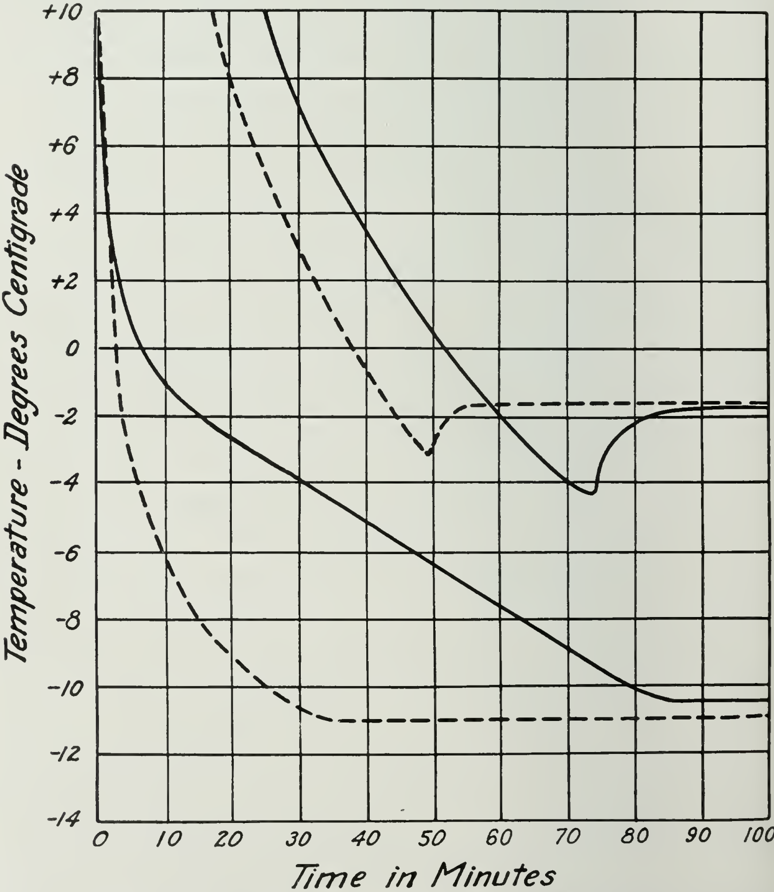

FIG. 12.—GRAPH REPRESENTING THE RELATIVE TEMPERATURES OF AIR AND TUBER IN SUPERCOOLING EXPERIMENTS

The upper curves represent the temperatures of the interior of the tubers and the lower represent corresponding air temperatures. The dotted lines indicate the temperatures in experiment No. 4 (Table 9) while the continuous lines belong to experiment 3 (Table 9). A comparison of these curves shows that where the air temperature dropped rapidly, as in experiment 4, the supercooling point of the tuber occurred more quickly and at a higher temperature than where the air temperature was dropped slowly, experiment 3. See further evidence of this in Tables 10 and 11 and accompanying text.

lowed through two experiments, in one of which the temperature fall was more gradual than the other. In both cases the internal temperatures could not be accurately recorded in the earlier stages owing to the fact that the thermometers were graduated only for lower temperatures. These data are, however, unimportant.

The apparent influence of the rate of fall of air temperature upon the supercooling range is shown graphically in figure 12.

Due to the sudden rise of temperature in the interior of the potato just following the supercooling period, all curves which represent the internal temperature of potato tubers have a profile similar to that represented in this graph (fig. 12).

TABLE X—THE INTERNAL TEMPERATURE VARIATIONS OF A POTATO WHEN THE AIR TEMPERATURE IS DROPPED SLOWLY TO —5°C (TABLE IX, EXP. 2)

Time	Temperature	
	Air °C.	Potato °C.
0	+10	
10 min.	0	
20 "	—1.0	
40 "	—1.8	
50 "	—2.4	
60 "	—2.7	
70 "	—2.7	+2.0
80 "	—4.6	+0.3
90 "	—5.0	—0.9
100 "	—5.4	—2.0
110 "	—4.6	—2.7
115 "	—4.8	—3.2
120 "	—4.8	—3.3
125 "	—4.7	—3.5
130 "	—4.9	—3.8
135 "	—4.6	—3.9
140 "	—4.8	—4.1
145 "	—4.7	—4.2
150 "	—4.7	—4.4
155 "	—5.0	—4.5
160 "	—4.7	—4.7
165 "	—5.0	—4.7
170 "	"	—4.85
171 "	"	—4.9
172 "	"	—4.91
173 "	"	—4.92
174 "	"	—4.95
175 "	"	—2.9
180 "	"	—1.8
185 "	"	—1.5
190 "	"	—1.4
195 "	"	—1.3
200 "	"	—1.3
205 "	"	—1.3

TABLE XI—THE INTERNAL TEMPERATURE VARIATIONS OF A POTATO WHEN THE AIR TEMPERATURE IS DROPPED SLOWLY TO —10.5 C. (TABLE IX, EXP. 3. THE SAME DATA ARE GRAPHED IN FIG. 12.)

Time	Temperature	
	Air °C.	Potato °C.
0 min.	+1.0	
5 "	+0.0	
10 "	—1.0	
15 "	—2.0	
20 "	—2.8	
25 "	—3.3	
30 "	—4.0	
35 "	—4.5	
40 "	—5.2	
45 "	—5.5	+2.0
50 "	—5.8	+0.2
55 "	—6.0	—0.3
60 "	—7.8	—1.4
65 "	—8.2	—2.9
70 "	—8.7	—3.2
71 "	—8.8	—3.4
72 "	—9.0	—3.8
73 "	—9.1	—4.2
74 "	—9.2	—4.1
75 "	—9.3	—2.9
76 "	—9.5	—2.5
77 "	—9.7	—2.4
78 "	—10.0	—2.35
79 "	—10.0	—2.3
80 "	—10.2	—2.1
85 "	—10.5	—1.8
90 "	"	"
95 "	"	"
100 "	"	"

SUMMARY

1. The potato crop suffers a considerable damage each year because of freezing injuries.

2. The most serious danger in Wisconsin and the other northern states is in autumn, when the early frosts come before or during the period of digging and handling the crop.

3. Similar danger exists in all the stages of transportation and delivery of the crop during the winter.

4. Where the tubers are frozen solid they immediately collapse upon thawing and because of their wet appearance are easily detected and sorted out.

5. In case of mild exposure only a part of the tubers may be so frozen, the rest appearing normal externally. Such tubers

are commonly held as satisfactory for storage, market or seed purposes.

6. If, however, these tubers are cut open, although all are externally sound, a certain proportion of them will usually show evidences of internal frost necrosis.

7. Such internal freezing injuries are not ordinarily visible externally, even after long storage, but in white-skinned varieties they may show as darkened areas on the skin, and in prolonged dry storage frost-necrotic tubers wilt faster than normal ones.

8. Frost necrosis is, however, at once apparent upon cutting open the tubers because of the darkening of the necrotic tissues.

9. The tissues of the stem end of the tuber are in general more sensitive to freezing injury than those of the eye end and the vascular tissues more sensitive than the parenchymatous.

10. As a result, tubers subjected to freezing temperatures when cut open may show internal discolorations of any of three types: (1) Ring necrosis, discoloration of the vascular ring, especially evident at the stem end when the tuber is cut crosswise; (2) net necrosis, in which the vascular tissue including the small thread-like phloem elements scattered through the pith and cortex are darkened; and (3) blotching, in which discolored tissue in patches, usually having vascular elements as centers, is distributed irregularly throughout the tuber.

11. Frost necrosis, especially of the net and ring types, is frequently confused with other potato tuber maladies, especially with the inheritable (non-parasitic) net necrosis and the Fusarium bundle browning, or "ring disease." It is especially important to differentiate these various types of trouble in potato seed stock.

12. Since the steam end tissues are the more sensitive, internal frost necrosis is most quickly detected by cutting off a little from the stem end of samples of suspected tubers, especially any such as show incipient wilting.

13. The necrotic discolorations develop promptly after the freezing (within a few hours, faster at higher temperatures), passing through pink to dark brown or black and ordinarily undergoing very little further change thereafter, even during long storage.

14. When drying out occurs in storage it is often evidenced internally by whitish air-filled patches or, in the more extreme cases, by small cavities within the blackened areas.

15. The turning sweet of potato tubers is often, but incorrectly, attributed to freezing. It is due to long storage at low temperatures which are, however, above the point of frost injury, and it will disappear if the tubers are again held at higher temperatures. Hence, while sweetness indicates that tubers have been held for some time dangerously near their freezing point, it does not indicate that they have been frozen.

16. There is a considerable difference between individual tubers in susceptibility to frost injury, even in the same lot of potatoes.

17. In general, neither variety, size, maturity, nor relative turgidity of potato tubers influences to any marked degree the liability to injury nor the type of resultant frost necrosis.

18. "Sweet" tubers may be more resistant to freezing than normal tubers. Müller-Thurgau showed experimentally that tubers with excessive sugar content regularly froze at lower temperatures than other tubers, but that the difference between the freezing points of "sweet" and normal tubers was not sufficient to be of economic importance. Our experiments in this case are too limited to be conclusive.

19. When wounds and bruises are healed over they apparently do not influence susceptibility to freezing. However, in tubers with freshly cut moist surfaces, freezing may begin at relatively higher temperatures and in such cases the injuries may consist of a freezing solid of the tissues from the cut surface inward.

20. In general, frost necrosis will appear in at least a portion of tubers which are subjected to a temperature of –10°C. for one hour, to –5°C. for two hours, or to –3°C. or slightly lower temperatures for several hours.

21. Although the actual freezing point of potato sap is about –1°C. the living tuber will endure long exposure to temperature at or near –3°C. without injury. This is because of the fact that the tissue must be supercooled before incipient ice crystallization can occur, but once this begins there is a sharp rise of the internal temperature to about –1°C., the true freezing

point, and the freezing injury continues to develop at this higher temperature.

22. The supercooling range seems to be dependent upon the air temperature and the rate at which this temperature is dropped. Thus, at –3.5°C. the supercooling point approaches the air temperature. If the air temperature is dropped slowly to –5°C. or below, it will approach –5°C. while if dropped rapidly to the same point it will be much higher, i. e., nearer –3°C.

23. Sprouts are more resistant to freezing than the tubers from which they arise, but uninjured sprouts on necrotic tubers often do not outlive the germination period, probably due to extensive vascular injuries of the tuber; hence if chilled tubers are planted they often fail to produce plants.

24. Plants produced by the frost-necrotic halves of experimental tubers grew more slowly than those from the control halves, but ultimately produced as large and healthy plants and as abundant a crop.

25. Necrotic symptoms never appear in the progeny of frost-necrotic seed potatoes.

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Farm Leasing Systems in Wisconsin

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CONTENTS

Farm Leasing Systems in Wisconsin

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Tenancy in Wisconsin is low in percentage as compared with that of many other north central states, yet there is a large number of farms operated by tenants, and in the older settled sections even an increasing proportion.

Tenancy is low in Wisconsin because land is relatively cheap in many counties, because farms are relatively small, because much of the population has sprung from European countries where ownership of a small farm is preferred to renting, because the livestock farming practiced in Wisconsin is not as well suited to renting as grain farming, and because there has been less speculation in land in Wisconsin than in most other states. These same reasons explain the distribution of tenancy in Fig. 1. It is highest in southern Wisconsin where land values are highest, but low in eastern Wisconsin where farms are small and the population is foreign. The high land values in the Rock River valley make tenancy fairly high as far north as Fond du Lac County. Large farms and grain farming in central and western Wisconsin produce much tenancy, even though land values are rather low. Beef-cattle farming reduces the number of tenants in Grant and Iowa Counties. Grain farming increases it in St. Croix, Pierce, Dunn, Jackson, Green Lake and Columbia Counties. Tobacco farming increases it in Dane County. Speculation around cities increases tenancy noticeably in Milwaukee, La Crosse, Winnebago and Dane Counties. Speculation in new land shows its effect in Forest, Vilas, Oneida and Washburn Counties. Juneau, Adams and Monroe have more rented land than one would expect with land values averaging in 1910 from $25 to $50 an acre, but these are the counties with large acreages of land farmed out to neighboring owners.

In 1910, out of 177,127 farms in Wisconsin, 24,654, or 13.9 per cent, were worked by tenants, as compared with 41.4 per cent in Illinois, 21.0 per cent in Minnesota and 15.8 per cent in Michigan. Besides the 13.9 per cent of farms rented, there were 681,396 acres worked under lease by neighboring owning farmers. Rented farms are larger than owned farms. Of the total land in farms in Wisconsin, 19.0 per cent was rented in 1910.

In 1910, slightly more than half of the tenant farms of Wisconsin were rented for cash and the rest were rented on shares. At cash rent, only in a few cases is livestock let with the land. At share rent, in a

majority of cases either part or all of the livestock is rented with the land. Leases covering both land and stock are called "land-and-stock leases." Share leases without livestock are "grain leases." Leases partly share and partly cash are called "share-cash leases."

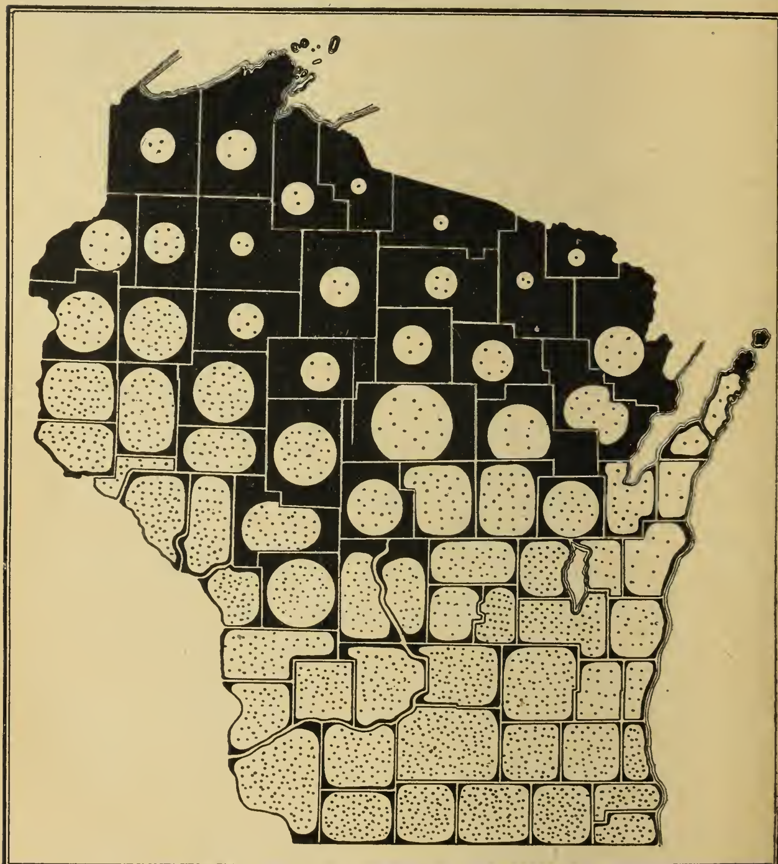

FIG. I. LAND IN FARMS AND LAND RENTED IN WISCONSIN, 1910

The black represents land not in farms, either because it has not been made into farms, or because it has been taken out of farms for some other purpose. Each dot represents 2,000 acres of rented land.

The following four general types of land-and-stock share leases are used in Wisconsin: (1) The half-and-half dairy lease, under which the landlord furnishes one-half the productive livestock and receives one-half the proceeds and increase of livestock; (2) the landlord's cattle dairy lease, under which the landlord furnishes all the productive livestock and receives one-half; (3) the one-half all-stock lease, under which the landlord furnishes one-half of all livestock and machinery

and receives one-half; (4) the one-third stock lease, under which the landlord furnishes all the livestock and machinery and receives two-thirds.

The grain leases used are of two kinds, the one-third grain lease, under which the tenant furnishes everything but the land, and gets two-thirds of the grain at the machine, and the one-half grain lease, under which the landlord furnishes part of certain expenses such as seed, twine and threshing. In some localities mixed grain-and-dairy leases are found.

By far the most important types of leases now in use are the regular cash lease and the half-and-half dairy lease. Following are sample leases of these types such as are now in force in Wisconsin.

Lease I.—Cash Lease

THIS AGREEMENT, Made this 5th day of January, 1915, by and between .... of ......, Lafayette County, Wisconsin, hereinafter called the landlord, and ...., of ......, Lafayette County, Wisconsin, hereinafter called the tenant.

WITNESSETH, That said landlord, for and in consideration of the cash rental and agreements hereafter named, does hereby lease to said tenant his farm of one hundred and sixty (160) acres, more or less, with all buildings and improvements located thereon, situated in Lafayette County, and described as follows: The W. ½ of the S. W. ¼ of Sec. 3 and the E. ½ of the S. E. ¼ of Sec. 4, all in Town ......, Range ......, East, *(Description)*

TO HOLD, for the term of one year from March 1, 1915, and thereafter for four more years, unless either landlord or tenant shall notify the other to the contrary on or before December 1st, 1915, said tenant paying said landlord therefor an annual rental of seven hundred (700) dollars. Receipt of one hundred (100) dollars of said rental for the first year said landlord hereby acknowledges. The remainder of the rent for the first year is to be paid in equal payments on September 1st, 1915, and February 1st, 1916, and is secured by two promissory notes for three hundred (300) dollars each, expiring on the before mentioned dates, bearing interest at six (6) per cent thereafter till paid, and signed by a third party approved by said landlord. And if this agreement is extended as before mentioned, then said tenant shall at once execute to said landlord eight promissory notes for three hundred and fifty (350) dollars each, expiring on September 1st and February 1st of the four successive years, bearing interest at six (6) per cent thereafter till paid, and signed by a third party approved by said landlord. *(Term renewal; Rental; Payments; Security)*

Said tenant further agrees as follows: to farm said premises in a good and husband-like manner; to put into crops all stubble land; to plow no land now seeded to grass, *(Duties of tenant)*

Seeding — except with the consent of said landlord; to perform all the work connected with sowing whatever clover and timothy seed said landlord shall furnish; to plant not more than twenty-five acres to corn each year, and to keep such corn reasonably free of weeds; to sell no hay or grain or roughage of any kind except with the consent of said landlord and to keep enough livestock to feed out all crops grown on said farm; to haul out all manure once each year and put it on the land which is next to be plowed for corn; to plant and care for all fruit trees provided by said landlord; to keep the land from washing by not plowing through seeded ravines and ditches and by keeping all washouts filled; to cut or dig all noxious weeds in time so as to prevent their going to seed; to cut the weeds in the fence-rows and around the buildings, and to the middle of the road; to keep all the fences on said farm in good repair and order, the landlord furnishing wire and staples, and lumber for gates; to cut all fence posts needed for repairs and for new fences, and to furnish half the labor for building all new fences; to keep the barns and other outbuildings in good repair, furnishing all ordinary labor, and to replace all doors and windows broken due to his acts or neglect, or those of his employees; to keep the windmill well oiled and pay for all ordinary pump and windmill repairs; to haul all materials which are to be used in making repairs or improvements on said farm, including the gravel for a 6 ft. foundation for a 16 by 40 ft. silo, and to board any workmen of said landlord engaged in making these repairs or improvements at the rate of four (4) dollars per week; and to observe all the rules of the ...... Mutual Insurance Company with respect to tank heaters, threshing engines, etc.

(Margin notes: Grass seed; Selling crops; Manure; Orchard; Gullies; Weeds; Fences; New fences; Building repairs; Windmill and pump; Insurance rules)

Said landlord further agrees as follows: to furnish clover or timothy seed enough to sow well and thickly at least fifteen acres each year, and to replace any last year's seeding that winter-kills; at the beginning of the lease to put in good repair the pump, windmill, cistern and all doors and windows, and thereafter to furnish material except posts for all repairs to buildings or fences not occasioned by misuse of tenant or his employees, and to provide one-half the labor for all new fences; to repair the roof of the dwelling house on said farm and at the beginning of the lease to make said dwelling house habitable in all ways; to build a 16 by 40 ft. silo and have it ready for the tenant's first corn crop; and to pay said tenant ten (10) dollars a year to cut and dig and use all possible means to eradicate the patch of Canada thistles growing on said premises.

(Margin notes: Duties of landlord; Grass seed; Repairs; Improvements)

It is further agreed that said tenant shall use as firewood first the tops of trees used as fence posts and after that the down and then as much dead timber as he may need;

(Margin note: Firewood)

House repairs

Taxes

Quittance requirements

that said tenant shall pay for all papering and painting and other inside repairs to the dwelling house on said farm and replace all broken glass in windows and doors; that said landlord shall pay all real estate taxes except the road taxes, which said tenant shall work out or else pay as an addition to his rent. There will be left on said farm on March 1st, 1915, six (6) acres of rye, 200 raspberry bushes, 25 currant and gooseberry bushes, and a year-old strawberry bed started from 200 plants, and said tenant shall leave the same as to amount and quality at the end of the lease. Said tenant may remove from said farm at the end of the lease enough feed to keep the livestock which he has kept on said farm until the new crop is ready for feeding; but no straw shall be taken from said farm. Said tenant shall not assign this lease nor under-let said premises; and said landlord shall have the right to enter upon and view said premises at all reasonable hours and to make repairs or improvements on said premises; and if either party shall in any respect fail to carry out any of the provisions of this lease, then the other party may hire the same done as herein written and the costs thereof shall be paid by the party failing to carry out said provision; and either party may terminate this agreement on March 1st of any year, except the first or the last, by giving notice on the December first preceding of his purpose to do so and paying or forfeiting to the other party the sum of one hundred (100) dollars, except that there shall in such case be added or subtracted from said one hundred (100) dollars all amounts due one party from the other resulting from failure to carry out any part of the lease.

Sub-letting

Right of entrance

Non-fulfillment

Termination

Payment for disturbance

Quitting of premises

And at the expiration of this lease, said tenant agrees to yield possession without further demand or notice of the above described land and premises, leaving them in as good order and condition as the same were in when said tenant entered upon them, loss by fire or inevitable accident and ordinary wear excepted.

And all the agreements herein contained shall bind said parties mutually, and their respective heirs, executors and assigns.

Witness the hand and seal of said parties the day and year first above written.

Signed, Sealed and Delivered in the Presence of

....(Seal)

....(Seal)

....(Seal)

Lease II. Half-and-Half Dairy Lease

Date

THIS AGREEMENT, made this 1st day of December, 1916, between .... of the city of ......, County of ......, State of Wisconsin, hereinafter called the landlord,

and ...... of ...... Township of the same county and state, hereinafter called the tenant,

WITNESSETH, that said landlord does hereby lease to said tenant his farm of 160 acres, known as the McGowan Farm, located in ...... Township of the County and State above named, together with all buildings and improvements upon it,

Term

Renewal

TO HOLD the same for a term of one year from March 1, 1917, and thereafter for four more years unless notice is given by either party in writing to the contrary before December 1st preceding, and thereafter from year to year unless notice be given as above described,

UPON the following terms and conditions:

Sec. I. Said landlord agrees—

Buildings and repairs

1. To furnish to said tenant the above described farm and premises, put all buildings in repair at the beginning of the lease, and thereafter keep same in repair, except as hereinafter provided.

Fences

2. To furnish all material for building and repairing fences, and pay for the labor of building all permanent line and field fences.

Clearing land

3. To pay for man labor expended in ditching and in clearing of brush, trees, stumps and stone, except as mentioned in Section II.

Improvements

4. To build during the summer of 1917 a new hen house large enough for 100 hens.

Sec. II. Said tenant agrees:

1. To farm said farm in a creditable and workmanlike manner, properly caring for all crops and all livestock kept upon it.

Labor

2. To furnish the labor for the above, the same to consist of not less than the continuous labor of two men from the beginning of the spring field work to the close of corn harvest, and such other labor as is needed.

Horses and machinery

3. To furnish the necessary horses, machinery and tools, except such as are mentioned in Sec. III, 4.

Hauling

4. To haul all produce to market, including milk, except that charges made by creameries or condenseries for hauling shall be deducted from cream or milk checks before they are divided.

5. To haul all feed, fertilizer and fence and building material.

Manure

6. To keep the manure hauled out, cleaning up the premises in spring and fall of each year.

Repairs

7. To make all ordinary repairs on buildings, especially to doors and windows, said landlord supplying all materials therefor except window glass.

8. To keep all fences in repair and build all temporary fences.

Care of fields

9. To remove from plowed land before sowing or planting all stones that have been plowed to surface.

10. To cut and destroy all noxious weeds in time to prevent their going to seed, handle quack grass in such manner as not to spread it, and take all reasonable care to keep the fields from gullying.

Sec. III. It is further agreed that:

Livestock

1. Said landlord and said tenant shall each furnish on March 1st, 1917, an equal number of milk cows, heifers, brood sows, and chickens, and these, together with the herd bull, which shall be a registered Holstein, shall be owned in common and in equal undivided shares. It is agreed that said herd shall contain not less than 24 milk cows.

Farm expenses

2. Each party shall pay one-half of all expenses (except labor) for threshing, silage-cutting, shredding, feed grinding, twine, feeds and fertilizer, and veterinary services (except for horses). All the feed (except straw) now on said farm shall be measured and the tenant shall buy one-half of it, or provide an equal amount of the same general kind and quality.

Seeds

3. Each shall furnish half the seed grain and grass and clover seed, except that on the last year said tenant works said farm, said landlord shall pay for all grass and clover seed.

Extra machinery

4. There are now on said place one manure spreader, one gasoline engine for pumping water, one milk separator and engine for driving it, one milk cooler, and a quantity of milk bottles and cans; and said landlord and tenant shall own these articles jointly and in common, said tenant paying said landlord one hundred and fifty ($150) dollars for a half interest in the same, one-half the purchase price of any of the same if replaced new, and selling his interest to said landlord at the end of the lease at such price as shall be agreed upon.

5. Said tenant shall furnish gasoline and batteries for said engines, and keep the engines, pump and windmill in repair.

Horses

Colts

6. Said tenant shall have undivided feed for his horses, but he shall keep not to exceed five horses, raise no colts without the consent of said landlord, pay all horseshoeing and horse veterinary bills, and make no charge to said landlord for horse labor, and if it is decided to raise colts, said tenant shall furnish the mare, said landlord shall pay the stallion fee, and the colts shall be owned jointly.

Additional land

5. Said tenant shall lease no additional land without consent of said landlord; but if it is agreed to lease such land, said landlord shall pay all the rent for crop land and half the rent for pasture land.

Taxes

6. Said landlord shall pay all taxes on property jointly owned, but said tenant shall work or pay the road taxes assessed to said farm.

7. Said tenant shall build fences for said landlord, ditch, clear land, and dig or otherwise destroy Canada thistles, if

he has time to spare from the regular farm work, at such times as said landlord shall request, and shall receive pay for the same at the regular prevailing daily wages.

Boarding workmen

8. Said tenant shall board all workmen hired by said landlord at four (4) dollars per week.

Sec. IV. It is further agreed that—

Management of crops

1. In general the fields shall be worked on a four-year rotation consisting of corn, small grain, clover and timothy, and pasture, and clover and timothy shall be sown with all small grain; but this plan may be changed at any time by agreement between the two parties if possible, or if such agreement is not possible, at the direction of said landlord.

Buying and selling

2. Said tenant shall sell or buy property owned or to be owned jointly only at the consent of said landlord.

Care of livestock

3. Said tenant shall breed no heifers till they are 21 months old, shall be responsible for all injury to animals due to their getting out through gates or unrepaired fences, and shall keep all cattle off the pasture and fields while the ground is soft, especially in the spring.

4. Said tenant shall weigh and record all milk from pure-bred cows.

Sec. V. The proceeds of said farm shall be divided as follows:

Division of proceeds

1. All crops and livestock products, and the increase of all livestock, shall belong half to each party, and said tenant shall pay one-half the proceeds from the sale of same to said landlord immediately upon receipt thereof, except that—

Milk checks

2. After deducting a charge for hauling, if there be such a charge, the buyer of the milk or cream of said farm shall make out equal checks to said landlord and tenant.

Milk

3. Said tenant shall first have not to exceed 3 quarts of milk daily for family use, but no butter.

Eggs

4. Said tenant shall first have eggs for family use, but not poultry.

Garden

5. Said tenant shall have all the produce of the orchard and garden on said farm.

Potatoes

6. Potatoes grown outside of said garden shall be divided half and half, and said tenant shall deliver the share of said landlord at his house in ....

Firewood

7. Said tenant shall have firewood sufficient for family use from the down and dead timber, and if this is not sufficient, from live trees cut where said landlord shall direct.

Sec. VI. At the end of the lease, the joint property shall be divided as follows:

Division at end of lease

1. Said tenant shall divide each class of livestock, as cows, yearlings, calves, hogs, chickens, etc., into two groups, and said landlord shall take his choice of the two groups

of each. In case the two groups cannot be made nearly equal in value, as for example, where there is an odd number of animals, the differences in value shall be agreed upon before the choice is made.

2. All hay, grain and fodder shall be divided by measurement and one-half left on the farm.

Quittance requirements

3. Said tenant shall leave all straw on the farm without compensation.

4. Said tenant shall leave 20 feet of silage in the small silo, the same as there is now at the beginning, and said landlord shall pay said tenant for half of such silage at the prevailing rate for silage of such quality.

Compensation

Sec. VII. If said lease be terminated on March 1 of any year by three months' notice as hereinbefore provided, said landlord shall reimburse said tenant for all grass and clover seed sown the preceding spring, and pay said tenant for all plowing done in the preceding fall at the rate of $2.00 per acre, and also for all other labor and expense connected with sowing fall grains.

Breach of contract

Sec. VIII. If said tenant shall fail to cary out any provision of this lease, it shall be the right of said landlord to enter upon and take possession of said premises and all the property jointly owned, and care for same till settlement can be made, which shall be done as nearly as possible according to the terms of this lease.

Arbitration

Sec. IX. If dispute shall arise over any of the settlements provided for in this lease, the matter shall be left to a board of three arbiters, one chosen by the landlord, another by said tenant, and the third by the two first chosen, and the decisions of this board shall be binding on both landlord and tenant.

Sec. X. Said landlord hereby reserves right of entrance upon said premises at all reasonable hours in order to work and make improvements as he shall deem expedient.

AND said tenant hereby agrees to quit said farm peaceably at the end of the lease.

WITNESSES	SIGNATURES OF CONTRACTING PARTIES
....	....
....	....

Provisions Common to Both Leases

In analyzing the provisions of Lease I. and Lease II. certain general differences between cash and share leases must be kept in mind. First, share leases, written in the form of Lease II, are in many respects partnership agreements, in which the landlord furnishes the

farm and part of the livestock and expenses, and the tenant furnishes the labor and the rest of the livestock and expenses. In a partnership, the policy of the busines is determined by mutual agreement. At share rent, therefore, the landlord has a larger amount of control and supervision of the farm operations than at cash rent.

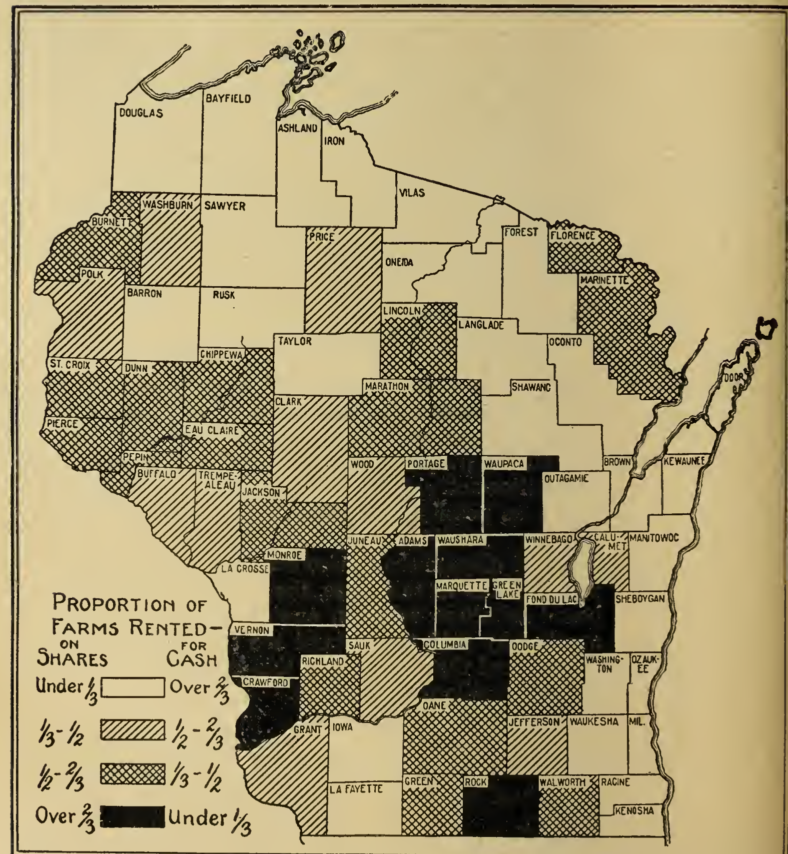

FIG. 2. DISTRIBUTION OF CASH AND SHARE LEASES.

Cash renting predominates in eastern and northern Wisconsin, in southwestern Wisconsin, and in a small group of counties in west-central Wisconsin, share renting predominates in the dairy counties of the Rock River Valley; and in the potato and tobacco sections of central and western Wisconsin.

Second, questions as to which party shall bear certain expenses can be settled at cash rent simply by adjusting the rent to fit. At share rent, however, custom apportions certain expenses to the landlord, and certain expenses to the tenant, and if any of these are changed, the customary shares of the two parties are changed. Landlords and tenants can always arrange expenses as they see fit, however, for if

the lease as made favors either party in one place, an equal offset can be provided in another, even if it requires a cash payment. In the discussion following, each of the provisions will be considered by itself as to its fitness and workability; the equality of the whole division of receipts and expenses will be considered later.

Third, any given share, such as one-half, is not the same on farms of all sizes and qualities with constantly rising and falling land values and prices. The share arrangement adjusts for some of these changes and differences automatically, but not for the larger part of them.

Fourth, at share rent the tenant gets only a share of the returns from any expenditure of money and labor, and he furnishes all the labor. He is therefore greatly interested in any improvements and methods of farming that will save him labor, and he is only part interested in those which increase the total farm income without reducing labor relative to it. Fifth, most share leases are made for shorter terms than cash leases.

Term. The two leases given are drawn for five and three years, respectively, with arrangements for renewal. Over half of the leases in Wisconsin are for either three or five years. A few are drawn for two or four years. More are drawn for one year, however, than any other term. Especially is this true of share leases in the older farming districts. Long leases are used in the newer northern counties and in the eastern counties, where what little renting there is, is for cash.

Renewal. Renewal provisions may have more to do with keeping tenants from moving than the term of the lease. The important consideration is that a date be set for notice of termination, and that this date be set far enough ahead so that both tenant and landlord can safely prepare in advance for the next year's operations. Three months or six months is the usual notice. If no date is set, the tenant may leave or the landlord decide to get a new tenant, any time up to 30 days prior to the end of the term, this being the length of notice required by law. The landlords who refuse to set a date because they want to keep their tenants guessing till the last moment are prejudicing their own interests even more than their tenant's. Since a lease can always be renewed anyway, the common "privilege of renewal" and "mutual consent" clauses have little value except as an expression of good intentions in advance.

Short vs. Long Leases.

The actual choice is between a short lease arranged so that it can be renewed readily, and a longer lease arranged so that it can be terminated easily. A landlord can get rid of an objectionable tenant under a long lease as well as under a short one, provided his lease contains a satisfactory termination clause. (See "Termination of Lease"). He will have more trouble, however, with a three or five-year terminable lease, for he may have payments for disturbances to arrange,

and compensation for work done on next year's crops. But he will escape many of the usual heavy losses resulting from year-to-year tenancy.

Landlords do not always realize these losses, because they come gradually. Besides, money lost in this way is never missed as much as money paid out of hand to get rid of an undesirable tenant. A one-year tenant even with the privilege of renewal can never bank on making his profit next year. He cannot afford to spend any extra money in keeping up the buildings and fences, cutting weeds and brush, and stopping washouts and gullies, because he does not know whether he will be on the farm to enjoy the benefits therefrom in the year following. He farms so that he can save the most money from the farm each year at a time. As a result, the farm gradually "runs down" and the buildings and fences go to ruin, and the rents that ordinarily would increase from year to year remain at a standstill or go backward. Or else the landlord spends large sums of money in repairing damages and losses after each tenant leaves. All the modern devices for controlling the crop rotation and sale of crops and regulating the amount of livestock kept do not greatly reduce these losses.

Another loss comes from the fact that one-year tenants cannot pay as high rent as three- and five-year tenants. It is in the second and third years, after they know their farms better and their neighborhoods better, and can grow better crops and livestock with less labor and expense, that they make the largest incomes.

The losses from short terms are even greater with share than with cash leases. With dairy farming, the dairy herd is the all-important thing. Neither landlord nor tenant can build up a good producing herd and have one-half of it replaced every year or two by a fresh lot of scrubs. Besides, no better way than this was ever devised for bringing contagious abortion and tuberculosis into a herd. The year-to-year share tenant has even more reasons than the year-to-year cash tenant for farming a year at a time, as is seen very clearly wherever such tenancy is not connected with dairy farming.

The best lease for Wisconsin farming is probably a three- or five-year lease with provisions for renewal, termination, compensation for disturbance and unexhausted improvements, and adequate settlement, by arbitration or otherwise, at the end of any year, or in case of breach of contract. At the end of five to eight years a Wisconsin tenant is likely to be looking for a larger or better farm to rent, or for a farm to buy, or the farm may have to be sold to settle up the estate. In England and Scotland, 19 and 21 year leases were long advocated but they were abandoned after a hundred years of experience with them. Rents change greatly over a long period, and as a result much injustice was done to landlord in periods when rents were rising, and to tenants when rents were falling. Besides, the tenants, even with their long leases, took all they could from the farms during the last years of the lease.

When the Term Begins.

When terms begin in the fall, the tenant either has to haul his winter's supply of feed, or else sell his feed and then buy again. Such things as corn in the shock, silage, and hay in the mow are hard to measure and value. In spite of these difficulties, most tenants move in the fall wherever much fall plowing or fall seeding needs to be done. The general opinion is that off-going tenants cannot be trusted to do this work well. The line of division between fall and spring moving passes from Waukesha County through the southern half of Dodge County and thence northward through Juneau and Adams Counties to Buffalo County. Tenants to the north of this line move more frequently in the fall, south of it in the spring. However, spring moving is common in potato sections. Some leasing arrangement is needed which will get the off-going tenants to do the fall work properly, so that more tenants can move in the spring. (See under "Quittance Requirements," page 19.)

Payments and Securities.

The usual plan under cash rent calls for two or three payments a year, the last one a month before the end of the term, and the others at regular intervals, or at times when sales are usually made from the farm. Monthly payments are becoming very common on dairy farms. Oftentimes a small payment is required in advance or when the lease is made out.

Under share leases, the milk or cream checks are divided monthly, or when received, usually by the persons buying the milk or cream. Large accounts, like receipts from livestock, are best settled immediately. Once a month is often enough to settle the small accounts like feed, repairs, and poultry receipts. Most share tenants keep fairly good accounts.

A promissory note properly countersigned and expiring at such time as the rent comes due is the commonest form of security for cash rent in Wisconsin. Chattel mortgages are sometimes applied to the tenant's livestock, or, under grain leases or wherever the crops are worth more than the tenant's equipment, to the growing crops instead. Some landlords ask for guarantors. Crop liens are also occasionally used in Wisconsin, but no law has ever been enacted which gives the holder thereof a prior claim over other creditors to the tenant's crops.

The security which landlords have with share tenants is the certainty of their payments from month to month and their control over the tenant's share in the jointly owned crops, livestock, and increase. No other security is needed. In case the landlord has "staked" the tenant, that is, has sold him a half of the herd on credit, or loaned him the money with which to buy a herd, then a chattel mortgage is the usual form of security. Such mortgages are frequently arranged so that a portion of the tenant's share of each milk check is automatically applied to the mortgage.

Following are examples of clauses creating various kinds of security.

"Said tenant does hereby offer, and said landlord does hereby accept, as surety for the rent one John E. R——————, whose guarantee of payment and hand and seal are hereby made a part of this lease."

"Said tenant hereby agrees to secure payment of the six hundred (600) dollar rental due October 1, 1912, by a good and sufficient chattel mortgage on all his livestock and machinery."

"—————— by a good and sufficient chattel mortgage on all crops as soon as the same shall be up and growing in the spring."

"Said landlord is hereby given a lien upon the crops sown on said farm and the same when harvested as security for the performance of all the conditions and provisions of said lease."

The promissory note given as security for rent is exactly like any other promissory note. Chattel mortgages and crop liens should be made out by competent persons. The following form may be used for a guarantee of payment:

For value received, I hereby guarantee, at such time as it shall become due, the payment of each and every rental mentioned in the within lease.

................................(Seal)

DUTIES OF TENANT AND RESTRICTIONS.

Wisconsin cash leases have had comparatively few restrictions, probably fewer than they should have, especially in the eastern counties, and as a result cash-rented farms have been robbed and run down much worse than share-rented farms. A few landlords go too far, however, putting in restrictions in the matter of crop rotation and choice of crops that have kept good tenants from doing up-to-date farming. Good tenants will not farm under such a lease, and consequently such landlords get only poor tenants.

Share leases really need fewer restrictions because the landlord usually takes a hand in managing the farm from month to month.

Crops and seeding. Restrictions in share leases as to crops are likely in southeastern Wisconsin to take the form of prescribing definite crop rotations, as in Lease II; in southwestern Wisconsin, limiting the acreage of corn; in Dodge County and northward, of requiring at least a certain number of acres of corn, or "enough to fill the silo"; in central Wisconsin, of designating the number of acres of corn, rye, oats, buckwheat and potatoes. Tobacco acreage is also limited in many leases.

Cash leases seldom restrict crop acreage except in southwestern Wisconsin, where landlords limit the acreage of corn so as to save their hillsides from washing. These same landlords also prohibit the plowing of the natural blue-grass pastures that mantle their limestone hills.

Keeping meadows properly seeded is one of the hardest things to

manage on rented farms. Tenants who are given a free hand are likely to break up old pastures and meadows because of their fertile, well-rested soils. Corn is the favorite crop for such fields. Some landlords, on the other hand, either restrict too much or do not provide for enough new seeding, so that in consequence rented farms have far more than their share of poor and run-out meadows. The important thing is to arrange to have new seeding always replacing the old. This is hard to arrange because clover seed often fails to catch, or new seeding winterkills. Lease I. leaves the matter in the hands of the landlord. If the tenant is required to seed a definite number of acres each year, he will have too much when it catches and comes through the winter, and not enough in other years. Following are additional provisions found in recent leases:

"There shall be 40 acres kept in meadow and no old meadow shall be plowed till new meadow has been seeded to take its place."

"Said tenant shall seed down as much as he breaks up each year, and he shall continue to sow seed until he has such an amount successfully seeded."

"No seeding shall be plowed which is not four years old."

"Not less than 25 acres shall be kept in meadow."

"Said tenant shall leave not less than 15 acres seeded down to clover and timothy at the end of the lease."

"Said tenant shall seed all small grain to clover and timothy, and break up no old sod except as directed by said landlord."

Grass and clover seed. Under share leases, bills for grass and clover seed are usualy shared equally, even with year-to-year leases. Occasionally landlords pay for the seed the last year on longer leases. (See under "Compensation for Unexhausted Improvements" page 21) Under cash leases, either the landlord pays for all grass and clover seed, as in the five counties in southwestern Wisconsin and a dozen more counties in northwestern Wisconsin, or the tenant pays for all the grass and clover seed, except that the landlord may do it the last year under many three and five year leases in force in the Fox and Rock River valleys.

Tenants should never be expected to buy grass and clover seed under one-year leases, either cash or share, nor under longer leases, unless they are to be reimbursed in case the lease is unexpectedly terminated. Under cash leases, it is usually best for the landlord to buy such seed, especially on light or thin soils. Some tenants prefer to do their own buying, however, because they say the landlords are "stingy with the seed." In either case the rent can be adjusted accordingly. Under land-and-stock share leases, it is proper to divide such expenses equally, but shift them to the landlord the last year of the lease, or in case of termination of lease. More and more landlords, however, especially in sections where cash and grain renting prevails, are buying all grass and clover seed and providing an offset for this in some other part of the lease. Recently many

landlords in Green, Dane, Jefferson, Rock and Walworth Counties have begun experimenting with this plan. Something must be done to improve the meadows on rented farms.

Following are two recent provisions as to the amount of seed furnished or sown per acre:

"Said landlord shall furnish 100 lbs. of clover seed and 50 lbs. of timothy seed each year, and said tenant shall properly sow and care for it."

"Said tenant shall furnish all grass seed, and sow it at the rate of ——— clover seed and ——— timothy seed per acre."

Selling crops. Land-and-stock share leases usually require mutual agreement or landlord's permission before crops can be sold. Both cash and share leases usually require all straw to be left on the farm, and some require hay and cornstalks in addition. Many share leases either require enough livestock to be kept to consume all feed grown on the farm or else specify a minimum number of cattle. Cash leases are also beginning to adopt this plan. Such restrictions as these may easily become too rigid under an unreasonable landlord.

Manure. Tenants will usually haul all manure gladly, but on strange farms they do not always know where it is needed most, and besides they are likely to slight the fields farthest from the barns, especially if working under one-year leases. Consequently the landlord is frequently given the right to tell the tenant where to put the manure, or some definite agreement is entered in the lease as to where the manure is to be spread.

The time of hauling is also given in many leases. This should never be so arranged that a departing tenant has to haul manure for his successor, unless the landlord wants to pay him for it. Following are provisions such as are sometimes given:

"Said tenant is to haul the manure now in the yard and spread it on the south field across the railroad track."

"All manure is to be thoroughly cleaned out in the fall and spring, except in the fall of the last year of the lease, said tenant shall perform this work only at the hire of said landlord."

"All manure is to be hauled out daily as long as the cows are kept in the stable, except when the ground is too soft for hauling, and all other manure to be cleaned out of the yards at least once a year."

Fertilizer. Very little commercial fertilizer is used on rented farms in Wisconsin, but a very considerable amount of fertility is bought in the form of feeds and concentrates. The tenant pays for half of this on share-rented farms, and all of it on cash-rented farms. He gets the advantage of it in the next year's crop, if he is on the farm; but in many cases he is somewhere else. The fertilizer values from concentrates last over several years, the same as do those of many commercial fertilizers. In England, tenants have long been allowed compensation for any part of this fertility which is not used up when they leave.

Some provision must be made for this in Wisconsin if tenant farming is to prosper.

Gullies and noxious weeds. Many landlords are now paying for all extra or unusual work needed in handling washouts and noxious weeds. They frequently are retired farmers and actually do the work themselves. Or they may hire the tenant or some member of the tenant's family to work with them. Or they may hire the tenant to do it on days when the land is too wet to work at so much a day or at a flat rate by the year. A tenant can be expected not to plow through the seeding in ravines and gullies, and to plow and cultivate the land so that it will wash as little as possible; also to keep his plow out of fence-row patches of quack grass and Canada thistle so as to keep them from spreading over the fields; and to destroy such weeds as interfere with his particular crops. And, if he is a one-year tenant, this is all that can be expected of him. Something more can safely be asked of tenants with longer leases, but not much more. Especially, tenants cannot be expected to clear a farm of noxious weeds left to seed and spread by a previous slipshod tenant. Checking a washout or destroying a thistle patch is too long a job for even a five-year tenant to handle alone. The landlord profits from such labor, and the landlord should help with it.

Keeping the farm tidy. The landlord should do his best to make his building and yard neat and tidy, and the tenant should want to do his share to keep up this appearance. This means such things as cutting the weeds in the yards, roads, and fence-row, and keeping tools and machinery under cover. If it does not always pay in dollars and cents, it surely does in satisfaction.

Fences. The commonest arrangements concerning fencing are:

When the landlord furnishes:

1. Materials.
2. Materials for repairs, and materials and labor for new fences and for replacing old fences.
3. Materials for repairs and for building all fences and labor for building and replacing line fences.
4. Materials, and one-half of labor in either *2* or *3*.
5. As in any of above, but the fence posts in the form of timber growing in the woods.
6. Materials and repairs.
7. All materials and labor.

The tenant furnishes:

1. Labor.
2. Labor for repairing old fences.
3. Labor for all repairs, and for building inside fences.
4. Labor for all repairs and one-half of other labor in *2* or *3*.
5. As in any of above, with cutting of fence posts in addition.
6. Definite amount of new fence.
7. Higher rent, or offset in some other part of lease.

A one-year tenant is not going to build any new fences if he can help it. Neither is a long-term tenant in the last years of his lease.

Any new fences which tenants do build if left to themselves are likely to be made about strong enough to last till their leases run out. Because tenants do not repair fences in proper time, they quickly fall to ruin. Landlords, therefore, soon weary of fence-building, and the tenant has to patch up the old fence for another year. Hence fences on rented farms are frequently "all toggles and no fence."

The very least, therefore, that a wise landlord can do is to furnish half the labor for building all new fences. Tenants can be expected to make such repairs as are necessary to keep cattle from getting out, but this is about all. Many landlords, however, are concluding that it pays them to take care of their fences after they are built so as to make them last longer. Some of them even up the costs of this by requiring the tenant each year to build a definite number of rods of new fence according to certain specifications.

Where the landlord hires fence work done himself, it is usually, but not always, best for him to hire the tenant to do the work on rainy or wet days. It helps out the tenant's income and makes him better satisfied.

UPKEEP OF BUILDINGS AND IMPROVEMENTS

Lease I. provides an arrangement which is becoming common in leases today. The house and premises are to be put in condition at the beginning of the lease, so that the tenant shall not suffer for the neglect or acts of his predecessor. After that, the tenant is to repair all breakages to doors, windows, etc., arising from his own acts or neglect or those of his employees, do the ordinary work on other repairs, assume full responsibility for all ordinary pump and windmill repairs, and make such repairs to the inside of the house as he desires. So many of the breakages to doors, windows, pumps, windmills, and so forth, are due to neglect and misuse that the landlord should not stand the resulting losses. The inside repairs, such as painting and papering, concern very closely the tenant's family and should be made by the tenant. Such repairs as shingling and outside painting should, of course, be made by the owner. The cistern should be put in condition at the start by the landlord, and after that cared for by the tenant.

Under such an arrangement the landlord must require the departing tenant to leave the premises in good condition, or else go to considerable expense to get things ready for the next tenant. With one-year leases, it will mean making most of the repairs himself between leases.

Improvements. Whenever a landlord agrees to certain improvements in making a bargain with a prospective tenant, the agreement should be written into the lease. If the tenant is to assist in the work, this should be put into the lease also. With the longer leases, the tenant can be expected to do the ordinary hauling and a reasonable amount of the common unskilled labor. He should not be expected, however, to haul without pay the gravel for a concrete silo, or dig a 10-foot basement for

a 40 by 100 foot barn, except that whenever the tenant has free feed for his horses he should contribute horse labor for such work free; nor should the tenant's wife be expected to board the landlord's workmen for nothing. Usually it is no hardship for a tenant to haul ordinary fence and building materials, inasmuch as he has trips to make to town anyway. Of course, the landlord need not always pay cash for such work; he can instead, for example, exempt the tenant from working the road-taxes, or hire some additional pasture or meadow land for him.

With one-year leases, the tenant can be expected to help very little with permanent improvements, unless he is to get pay for his work in case he has to move within, say, three years.

Firewood. The tenant should understand that trees are the property of the landlord and that he has no rights concerning them except as granted by the landlord. Lease I. contains the usual provisions on this subject. Sometimes it is stated in addition that the tenant must pile and burn his brush. In other leases, the tenant is allowed firewood, but he must cut no trees except where the landlord directs.

Firewood is an important item in the living expenses of the tenant's family, and many farms today have no woodlots. There is no reason why tenants should have free fuel any more than free clothing, except that custom in the past has given it to them, and cash rents and share-leasing arrangements have been adjusted to this custom. As long as farms were well-stocked with timber it was good economy to give the tenant fuel and make the rent to fit. Therefore, wherever fuel is not furnished, the fact should be clearly recognized when the lease is made out and rents and terms of share leases properly adjusted.

Who Pays the Taxes

Under share rent, usually each party pays the taxes on the part of the property which he owns separately, and half of the taxes on the jointly owned property. The tenant usually works or pays the road taxes. Lease II requires the landlord to pay the taxes on the jointly owned property as an offset to certain machine bills. Lease I gives the usual practice under cash rent contracts. In northern Wisconsin, however, and a few of the counties near the Illinois line, the landlord frequently pays the road taxes along with the other taxes. The new road system is bringing this about. If the lease reads, "the tenant shall work the road taxes" and, as frequently happens, the tenant is given no chance to work them by the road officials, it is doubtful if he can be made to pay them in cash. The newer leases therefore frequently read "shall work or pay the road taxes." A few cash rent contracts require the tenant to pay the real estate taxes, but this is not good practice and should be discouraged.

When the Tenant Goes

Quittance Requirements. These are requirements to leave certain things on the farm at the end of the lease in the same amount and

quality as at the beginning of the lease. This is the plan most generally used in Wisconsin to bridge over the gap between the going and coming tenant and keep farming operations continuous. Under all types of leases, share or cash, tenants are commonly required to leave their strawstacks, and sometimes they must leave their cornstalks in addition. When the change is made in the spring, the only other requirements usually needed are those which specify a certain number of acres of clover or timothy seeding or rye or winter wheat. In some sections the departing tenant is required to leave feed enough to keep the new tenant's livestock till the new crop is ready, especially feeds that are hard to move, like silage.

With fall moving, however, either the tenant must haul his whole winter's feed or a large number of quittance requirements must be provided. The second plan is usually adopted as the better of the two evils. The departing tenant harvests his crop, measures up an amount equal to what he found on the farm at the beginning of his lease, sells the surplus, and drives his cattle to his next leasehold. The change is made early enough so that the new tenant has time to do his fall plowing, but too late for sowing winter grains. The corn is either put in the silo or left in the field in the shock. The amounts to be left for the next tenant are usually stated in an inventory, which is made part of the lease. Following is a sample of such an inventory:

Silage—within 8 feet of top of silo when settled.
Corn in crib—6 feet in the east crib.
Corn in the field—14 acres in shocks.
Hay—east mow to top of ladder, clover; west mow, 12 feet, clover and timothy.
Oats—1200 bushels, measured in the bin.
Barley—200 bushels, measured in the bin.

Quittance requirements do not work very well on the whole. No one enjoys "paying for a dead horse." It is hard for a tenant to do work thoroughly well from which his successor is going to benefit wholly. Grass seeding the last year may fail to catch, wheat may winterkill, or crops spoil; and the landlord finds it hard to compel the tenant to make up the deficit. Such requirements should, therefore, be used only where they are necessary to prevent wasteful practices.

One difficulty is in the matter of the quality of the feeds left on the farm. Corn in the shock may be very poor the last year of a lease if the season is unfavorable or the crop is not properly tended. Silage may vary as much as corn in the shock. The same is true of hay in the mow. The only way to handle this is to provide in the lease for bargaining with the departing tenant as to the quality of the crop, and calling in an impartial board of appraisers in case of disagreement.

Another difficulty is that crops may be short the last year. Leases usually provide that the tenant must make good in cash such shortages, paying at the market rate at the time, or at a rate agreed upon

in advance. The latter plan is the fairer, because in a year of crop failures when prices are high, it may ruin a tenant to make up his deficits.

Under share leases, only the landlord's share of the necessary feed is usually to be left. This means that each new tenant must either haul his share of feed from his last leasehold or else sell and buy again. Since silage cannot be hauled to advantage, the departing tenant leaves his share as well as the landlord's. He is compensated for this by an equal amount left by the tenant before him. Probably this plan should be extended and made to apply to all feeds. The objection to it is that it would transfer to the landlord the carrying of the whole investment in feed on hand. The landlord would virtually provide all the feed for the tenant till the new crop was harvested. The tenant would not pay back this feed till the end of the lease. But this difficulty could be obviated by requiring each tenant to buy half of the feed on hand at the beginning of the lease, and sell half of it back to the landlord at the end of the lease. Or the transactions could be arranged directly between the in-coming and the out-going tenant as it usually is in England. (Such a plan would be closely related to "compensation for unexhausted improvements" described below). In effect, this plan would amount to a quittance requirement in feed equal to the remainder of a normal year's crop at the time of moving, the in-coming tenant being obliged to buy his proper share of this upon date of securing possession. It would require, it is true, considerable bargaining at the beginning and end of the lease, but these are the very best times for landlords and tenants to bargain. At any event, it would be better than hauling a whole winter's supply of feed, or even a spring's supply.

Quittance requirements in fall plowing, winter grains, seeding, and hauling manure should be imposed only where strictly necessary to keep up crop rotations or insure proper soil conditions for the next year's crops.

"Compensation for unexhausted improvements" is the name for a plan used in England which bridges over the gap between tenants much better than quittance requirements. As this plan is used in England, a farm is rented from year to year, but with the understanding that in case a tenant is required to leave, he is to be paid for all work which he has done from which he has not had time to derive the full benefit. The tenants therefore go ahead just as if they owned the farms and always intended remaining upon them. They buy lime and fertilizer and put it on the land, tile-drain, ditch, clear forest, lay down pasture and meadow, make repairs and erect barns and sheds. The landlord must consent to these improvements only if they involve a large investment. What the tenant receives as compensation when he leaves is partly a matter of lease, partly of custom, and partly of arbitration. Either the new tenant pays the departing tenant direct for these improvements, or he pays the landlord, who has settled with the departing tenant.

The beginnings of such practice have already appeared in Wisconsin in such provisions as the following:

"Said landlord shall pay said tenant at the rate of two (2) dollars per acre for all fall plowing he shall do in the last year of the lease."

"Said tenant shall be paid 25 cents per load for all manure which he shall haul after harvest in the last year of the lease."

"Said landlord shall pay said tenant two-thirds of the original cost of the silo at the end of said lease." (3-year lease).

Such provisions as these could well be extended to cover such things as grass and clover seeding, winter grains, small fruits, house repairs, new fences, fence posts, seeds, feeds and concentrates, manures and fertilizers. The compensation in the case of manures and fertilizers should be in proportion to the amount of the fertilizer value that is still left in the soil. Extensive experiments have been conducted at Rothamsted, England, to determine the fertilizer values remaining at the end of each year after application.

Compensation for unexhausted improvements is needed more with one-year lease than with longer leases. At present in some sections tenants remain as long on each farm under one-year leases as under longer leases; but still they never know what the next year will bring and so plan each year's profits alone. Could they be assured of compensation, they would go ahead on a long-time basis. Although the plan is used only with cash renting in England it is equally applicable to share renting. The only difference would be that the tenants own only a part interest in many expenditures on share-rented farms.

Fruits. Lease I. includes among its quittance requirements a small-fruit garden. Unfortunately many tenant farms are without small fruit. A landlord should try such a plan as given here, or some plan providing compensation for unexhausted improvements, or else provide the small fruit himself. He cannot afford to let his tenants live without these pleasures of life on the farm. A contented tenant family is worth much more to him than the cost of the small-fruit garden.

Termination of lease. Leases for more than one year usually are arranged so that they can be terminated at the end of any year by the giving of notice, usually from 60 days to 6 months in advance. Even without a breach of contract, things may happen which make the landlord or tenant want to end the lease, and some peaceful way of doing this should always be provided. Most termination clauses provide that the tenant is to receive full compensation for all work done for the next year's crop. The landlord recovers this amount from the purchaser in case he is selling his farm, or from the new tenant.

Payment for disturbance. With termination clauses is frequently combined some provision for "payment for disturbance," as this expression is used in England. If a tenant who has been doing honest farming on a long-time basis is asked to move, he is entitled to some recompense in addition to pay for work done on next year's crop.

He has learned how to handle his farm; he has planned many things that have not yet borne fruit. The landlord is likewise entitled to some recompense if his plans are disturbed by the tenant.

Lease I provides for 3 month's notice and $100 for disturbance, but nothing for compensation. Following are two other arrangements.

"To hold for five years from March 1, 1912, unless terminated by either party by giving notice in December preceding and paying to the other party one hundred (100) dollars and said landlord paying to said tenant two (2) dollars an acre for all fall plowing and fall seeding done and market price less cost of hauling to market all fall grain sown.

"This lease may be terminated at ninety days notice prior to any March 1st, by written notice and forfeiting from said annual rental four hundred (400) dollars at the end of the first year of said term, three hundred (300) dollars the end of the second year of said term, and one hundred (100) dollars at the end of the fourth year of said term. In case of the death of either party, this lease terminates on March 1st following."

Sale clauses. Notice of termination and payment for disturbance are also provided in most of the following sale clauses allowing the landlord to sell the farm during the term of the lease:

"Said landlord reserves the privilege of selling said farm at any time, and said tenant shall vacate the premises at thirty days notice, receiving payment for all work done not yet realized upon, but if said tenant shall have his spring grain planted he shall not be required to leave said farm till November 1st."

"In case of sale of said farm, said landlord shall give said tenant thirty days' notice of time to move from said farm, and shall pay him for work done at the rate of seventy-five (75) dollars per month, together with all moneys spent by said tenant for labor, seed and feed, but there shall be subtracted from this amount all moneys received by said tenant to date from the operation of the farm."

"Said landlord may sell said farm at any time, but he hereby agrees to compensate said tenant for all work done not yet realized upon, and to pay for all damages he may cause to said tenant, the amount of all these payments to be awarded by a committee of three, one of whom shall be chosen by said landlord, another by said tenant, and the third by the two first chosen."

"Said landlord may sell said farm at any time, and said tenant shall move off on March 1st following, but said tenant shall always have sixty days notice to leave, and shall receive one hundred and fifty (150) dollars as damages, except on the last year of the term."

Failure to carry out lease. Lease I. has the sensible remedy for failure to carry out the lease. It enables either party to hire the work done which the other has neglected to do, and to collect the cost of the same from the other party; and if this is not satisfactory, to terminate the lease upon reasonable notice the following March. The various clauses in leases empowering the landlord to "expel the tenant forthwith," or "at his option," or to declare the lease "null and void," are

mostly intended as scareheads. The wise plan is for the landlord to get along as best he can with his tenant till the end of the year. If the tenant is clearly beyond all reason, then according to law, he can be ousted at any time on 30 days' notice without provision in the lease.

PROVISIONS FOUND ONLY IN LEASE II.

Man labor. Share leases encourage tenants to farm many acres with a small amount of help. Landlords tell them they are mistaken, but tenants pay the labor bills and have a different view. Lease II requires the tenant to hire a definite number of men. Another arrangement now working successfully wherever tried in the share-renting belt in southern Wisconsin requires the tenant to hire a minimum amount of help, as in Lease II, and then requires the landlord to pay half or some other part of the wages of an additional man. This plan frankly recognizes that the tenant will make his largest income with, say, one hired man and that any additional help, though it may swell the total farm income, and the landlord's half of it, will cost him more than he gets back, and therefore requires the landlord to pay his half of the second hired man. More landlords follow the practice of helping the tenant themselves when work is pressing, or hiring extra day help for him, or adding something to the hired man's wages so as to get a good one.

Many landlords oppose this practice, saying the bars must not be let down for the tenants at any cost. Offsets can always be provided, however, in other parts of the lease. The present plan of making the tenant hire all the labor is not going to bring about the kind of farming that is needed today. If landlords will not change, as surely as farming becomes more intensive, cash rent will drive out share rent as it has in England. If they adopt the plan proposed, then as farming becomes intensive and more labor is hired on the half-and-half basis, the tenant's share in the proceeds will gradually fall.

Wherever a tenant does some special kind of farming requiring extra labor, such as running a milk route, or raising sugar beets, then the case is very clear that the landlord should help pay for the extra labor.

Horse labor. In most parts of the state with land-and-stock share leases, the tenant has undivided feed for his horses, but usually the number of horses to be kept is limited in some way. In a few counties where grain leases have only recently passed away, the tenant has undivided hay and straw, but must feed his own grain. The new way is by all means best for dairy farms. It is expecting too much of a tenant to ask him to keep accurate measure of all the hay and grain he feeds his horses. Occasionally a tenant abuses the privilege of feeding undivided grain by going into the horse-trading business, bringing home worked-out horses, feeding them up, and then selling them at a profit. A lease can be so made as to guard against this if necessary.

Colts. Some of the usual arrangements with respect to raising colts are the following:

1. Tenant furnishes the brood mares, landlord pays the stallion fee, and the colts are owned half and half.
2. Tenant is forbidden to raise colts.
3. Tenant must have the landlord's consent to raise colts.
4. Tenant may raise one colt of his own each year and feed it undivided feed.
5. Tenant may have undivided feed for only one colt of his own at a time.
6. Tenant may raise colts, but must feed his own hay and grain.
7. Tenant owns brood mares and colts half-and-half with the landlord, exactly as the cattle are owned in half-and-half share leases.

Good farm practice usually demands that colts enough be raised to take the place of the old horses as they wear out. The tenant should be allowed to farm according to this practice. The landlord, however, is probably entitled to one-half of the increase here, if he has paid the stallion fee, and the colt is kept till it is ready for work. Nos. 4 and 5 are not in very common use. When colts are raised in considerable numbers, the No. 7 arrangement is the fairest.

Tools and machinery. Until recently the tenant has provided all the tools and machinery with half-and-half share leases. Modern farming, however, is requiring a sudden very great increase in farm machinery, more than most tenants can stand, and landlords who want to keep their farms abreast of the times find it necssary either to provide such machinery themselves or else join with their tenants on halves. This is especially true with specialized types of farming, such as supplying city milk. Lease II is adapted to such farming. Gasoline engines, cream separators, milking machines, ensilage-cutters, and manure spreaders are frequently owned half-and-half, one party buying out the other at the end of the lease. Lease II requires the tenant to provide the gasoline and keep the extra machinery in repair. The landlord offsets this elsewhere in the lease by paying all the taxes on jointly owned personal property.

Hiring tenant labor. The tenant is the man who can do the landlord's extra work cheapest and best, because he is on the job, has a team handy for hauling, knows where the materials are, and usually has time to spare for it on rainy days and when the land is wet. Besides, it will help out the tenant's income and make him more contented. It is always well for the landlord to be on hand to supervise such work.

Hauling. The tenant always hauls the feed and the produce on land-and-stock rented farms. Where large amounts of feed are bought, or where milk is hauled a long distance, this is something of a hardship upon the tenant, and probably the landlord should make some allowance for it. Nowadays, however, most milk and cream is gathered by the buying companies. In some cases the tenant is made to pay the hauling charges, but ordinarily these are deducted before the milk check is divided.

On farms near cities, landlords frequently pay their share tenants for hauling manure from town, usually at the rate of 50 cents a load.

HOW LIVESTOCK IS DIVIDED

With land-and-stock share leases, the productive livestock is almost always owned in common. A landlord renting for the first time who rents to a beginning tenant usually sells him one-half of the cattle, hogs, and so forth, then on the place. The price is settled upon by agreement or by an appraisal. If the on-coming tenant has a half-share of livestock, the beginning landlord may sell off part of his livestock, at auction. Most landlords will, of course, have only a half-share of livestock to match the tenant's half-share. When the two shares are brought together, each party owns a share of the whole. Exception is made to this sometimes when landlord or tenant have some purebred animals which they insist upon owning separately. (See under "Improving the herd," page 29.)

Common ownership presents the serious difficulty that the two shares of livestock may differ greatly in age and quality. The tenant should not be allowed to match heifers against milk cows, nor, as is frequently the case at present, to match an unequal number of poor milkers against the landlord's high producers. High-quality dairy farming will never develop on share-rented farms till some way of meeting this difficulty is generally adopted. At present, because difference in quality of the two shares is frequently ignored, landlords do not think it worth while to develop good herds. As a result, tenants' herds are sometimes better than landlords' herds. The only methods now used of meeting this difficulty are those described in the following articles from recent leases:

"A board of three appraisers, one chosen by the landlord, another by the tenant, and the third by the first two chosen, shall appraise the parts of the dairy herd furnished by the landlord and tenant, and the party whose part of the herd is less valuable shall pay the other party one-half of the difference between the values of the two parts of the herd; and thereafter the herd shall be owned jointly and in common." Or:

"Said landlord and tenant shall agree upon the value of the herd furnished by each, and whichever party has the less valuable herd shall pay the other party one-half of the difference or buy sufficient cattle at a price agreed upon by both landlord and tenant to make the shares equal; and thereafter the herd shall be owned jointly and in common."

The number of cows. Lease II. states that a definite number of milk cows must be kept. About a third of the half-and-half leases have this provision. Another common provision prohibits the selling of any crops from the farm, or requires that enough stock be kept to use up all the feed grown on the farm. In many cases, nothing is said about the number of cattle and selling feed, but the landlord must consent to all sales. Leases should not be too rigid in this matter. Crops sometimes produce surpluses, which the tenant cannot very well feed out without waste during the last year of the lease. Either landlord or tenant may not be able to buy the extra livestock needed to use

up the feed. If the landlord does not want any feed sold from his farm in case of a surplus crop, he must often be prepared either to buy this surplus or to help the tenant buy the extra livestock.

Feed. The tenant must, of course, provide half of the feed for the productive livestock This means that when he comes to a farm he must either bring with him an amount equal to that now on the farm owned by the landlord, or buy from the landlord if he has enough for both, or buy out the departing tenant. (See under "Quittance Requirements," page 19.) Purchased feeds are, of course, divided in the same way. The amount of feed to be purchased is decided by mutual agreement, but is sometimes provided in the lease or left to the will of the landlord. It should be clearly recognized that buying large quantities of feed puts a share tenant at a disadvantage, for not only does he have the extra labor of hauling the feed and feeding it to the livestock and caring for the extra livestock, but he also loses his share of the benefit from the extra fertilizer value of the manures produced unless he remains on the farm for at least two more years, or unless some form of compensation for unexhausted fertilizer is provided in the lease.

Harvesting and threshing expenses. Half-and-half with such expenses is the usual arrangements under land-and-stock share leases. Twine is sometimes paid for altogether by the tenant. The machine work of threshing, silo-filling and shredding is almost always shared equally, in spite of the fact that shredding directly reduces the tenant's labor. Twine used for binding corn also saves tenant labor. The coal and oil for engines is also shared equally in most cases. In a few localities the landlord pays the tenant in part for feeding the threshing crew.

Breeding fees. Bulls and boars are usualy owned in partnership. When not, the landlord frequently pays the fees to offset the tenant's extra labor.

Management of the farm. A few general restrictions are usually put into share leases, and the rest is left to be determined from week to week. Some landlords make themselves virtual managers in their share leases and determine the whole policy of the farm. Other landlords leave matters to be settled by mutual agreement. In such cases, there needs to be someone to say the final word in case of difference of opinion, and this, of course, must be the landlord. Some of the details left to be settled from time to time, or partly provided for in the leases, are crops and seeding, buying and selling of livestock, feeds and produce and the care of livestock.

Buying and selling. Large landlords who make renting farms on shares a business usually do all the buying and selling themselves, collect the money and divide it with the tenant. More of them require the tenant to obtain their consent before buying or selling in any large amount. In actual practice the landlord interferes very little with the tenant's plans in such matters, and many tenants do most of the selling upon their own judgment. Of course, the landlord has a clear right to be consulted in such matters, but he can delegate the matter to a tenant if he wishes.

Care of livestock. Lease II. has a number of definite requirements as to care of the livestock, breeding, etc. Some leases go farther than

this and describe the ration for the milk cows. Following are two examples of this:

"Not less than 10 tons of bran or other concentrates shall be fed to the cows in milk."

"In general, one pound of ground grain or mill feed shall be fed each cow for each four pounds of milk produced."

Such provisions as the foregoing are rather uncommon, however, and still in the experimental stage. Undoubtedly some new developments along this line are in prospect.

Division of proceeds. Besides his half of the crop, produce and livestock sales, and of the increase, the tenant is allowed a large part of the living for his family, usually including rent, firewood, milk, eggs, potatoes and garden produce and sometimes butter and meat.

Milk and butter. Following are the usual arrangements:

"The tenant shall have 2 (or 3) quarts a day for family use."

"The tenant shall have milk for family use, but no butter."

"No butter shall be made on the place, and the proceeds from the milk shall be divided equally at the creamery."

"The tenant shall have 12 pounds of butter for family use each month before the milk check is divided."

"The tenant shall have free feed and pasture for one cow of his own."

The old arrangement was either the last one, for the tenant to have a family cow and make butter, or for the tenant to save out milk and make his own butter for family use. The practice still persists in many counties in central and western Wisconsin. In certain other counties, such as Dodge and Green Lake, the tenant has his butter out of the milk checks. In southern Wisconsin, however, the tenant pays for his butter. The tenant always has free milk.

Garden and orchard. All leases specify that the tenant shall have a free garden plot of a quarter or half an acre, and many of these add, "in return for working the road taxes." The exchange is no longer an even one, even allowing for the time spent in working the garden, but there is no harm in it, because other changes have favored the tenant. However, the garden ought to be larger than it usually is, and it ought to contain more fruit trees and small fruit, even if the landlord has to provide them. And no landlord can afford to ask a tenant to bother with dividing small fruit with him, unless he wants to go out and gather his own share. As for potatoes, some landlords purposely keep the garden plot small so that the tenant will have to grow his family supply of potatoes elsewhere and thus give him a half of them. Others ask only that the proceeds be divided in case potatoes are sold.

Poultry and eggs. About half the time the poultry is owned half and half, and the tenant is expected either to count the eggs when they are gathered, and the young birds when mature, and deliver one-half to the landlord, or else the tenant is allowed eggs and poultry for

family use before the division is made. Neither plan works very well. The poultry is usually looked after by the women, and they have a feeling that they earn all they get from it. As a result, some landlords are now asking for only one-third of the poultry receipts.

The other plan in common use is to let the tenant keep a limited number of hens, usually 50, 75 or 100, and give him all the proceeds. The only difficulty that has arisen is that the flock is sure to exceed the limit after a season's hatch and the tenant does not always sell his surplus when he should. Accordingly, a date is sometimes set when the flock must be reduced to the set number.

A few landlords are trying out a third plan, which requires the tenant to deliver to the landlord a definite number of eggs, say four or five dozen, for each hen kept, or to pay the landlord a definite sum, say $1, for every hen kept.

Most landlords do not want their tenants to go into the poultry business wholesale; but they do want them to keep enough to clean up the usual wastage of grain and feed around a farm. This is certainly in the interests of good farming. Still, none of them can afford to quarrel with a good tenant over such a detail as poultry receipts.

When the Lease Ends

Division at end of lease. There are about four ways of dividing the livestock at the end of the lease.

1. The first of these is described in the first paragraph of Sec. VI. in Lease II. The others are as follows:

2. "The landlord and tenant shall draw cuts to see which shall choose first and they shall then choose alternately until all the cattle are chosen. The brood sows and pigs shall be divided in the same manner. If there is an odd number of any kind of livestock, the animal to be chosen shall be sold and the proceeds divided between the two parties."

3. Landlord or tenant buys the other party out at a price settled by bargaining, or by appraisal in case of disagreement.

4. The livestock is sold at auction and the proceeds are divided. (This method is seldom used except as a last resort.)

Landlords sometimes complain that with Nos. 1 and 2 the tenants often get the better of them because they know the cattle better. The option to buy at an appraisal price, reserved in No. 3, is not favored by many tenants, because it may give the landlord a chance to buy away from them the herd of cattle which they are trying to breed up preparatory to renting for cash or to buying a farm.

Improving the herd. It will be apparent that even the plan of equalizing the value of the two herds described above (page 26) when combined with the usual plans for division at the end of the lease, does not encourage the building up of good herds on rented farms. One of the questions ambitious landlords in the dairy sections are forever asking is, "How can I build up a good herd if I have to divide it with every tenant who leaves my farm?" Each tenant who comes to a farm

ordinarily brings a fresh lot of grades and scrubs, and when he goes, according to the usual terms of the leases, he takes his share not only of the progeny of the landlord's better animals, but also of the better animals themselves. Some of these landlords want to keep purebred cattle on their farms. Others are interested only in developing high-producing herds.

Following are a few plans that are being tried now and then to overcome the foregoing difficulties:

First plan: The herd is owned in common and divided in the usual manner at the end of the lease, but the landlord carefully selects a tenant who has a herd which he thinks will combine with his to advantage. The difficulty with this plan is of course that a landlord who has a well bred herd finds it hard to procure a tenant who can match it.

Second plan: The landlord sells a half share in his herd to the tenant and thereafter the herd is owned in common. In some cases the lease allows the landlord to buy back the tenant's share of the herd at the end of the lease at a price determined by appraisal. However, few tenants favor such an arrangement. The chance to build up a good herd on the foundation of the landlord's herd is one of the things that makes them acept the terms of the usual share contract; and if this chance is taken away many of them will not be share tenants. In other cases the herd is divided in the usual way at the end of the lease. This means that the tenant gets part of the landlord's original herd as well as part of the young stock. From the standpoint of the landlord, it is equivalent to selling off half his herd, quality as well as quantity, every three or four years. It takes a long time to build up a herd at this rate.

Third plan: Landlord and tenant own their herds separately, and the original stock, or so much of it as is still left, is retained by each party at the end of the lease. This makes it possible for the landlord to have purebred or high-grade cattle, although the tenant does not. In some cases the difference in the value between the two herds is adjusted and the increase of young stock is divided half and half in the usual way. Under such an arrangement, the two parties share on even terms, and the tenant gets his pay for the extra care required by purebreds in the extra value of his half of the increase. In other cases, the difference in value is not adjusted, but the landlord has first choice of his half of the increase of purebred heifers at a certain age. Receipts from sales of bull calves are divided equally. Under still another arrangement the landlord agrees to buy all the increase of young stock of the tenant at a certain age, or at time of division of the herd, at a price agreed upon in advance, the price being enough more than the price for grades to repay the tenant for all extra care required. Differences in the value of the herds may or may not be equalized at the start, the price of the young stock being adjusted to fit either arrangement.

Fourth plan: Where the landlord owns only a few purebred cattle, he retains separate title to these, pays for half their feed, and receives

half of the milk receipts from them and half of the heifers at a certain age. First choice may be provided if desired. The rest of the herd is handled in the usual way.

All plans providing for separate ownership of cattle are open to the objection that if accident or sickness happens to one of the landlord's cows, suspicion is likely to arise that the tenant has not given it proper care, or has not fed it properly, and this suspicion is as bad for the landlord as it is for the tenant. For this reason, separate ownership has given place to ownership in common. Nevertheless, some of the foregoing plans may well be worth a trial.

Arbitration. There ought always to be some way provided in the lease for tenant and landlord to settle their differences without going to law. Lease II. provides for arbitration by a board of three. This plan is being used more and more and is working well. Occasionally a lease nominates a single person, or the College of Agriculture, to act as arbitrator and settle differences.

LEASE III.—LAND-AND-STOCK CASH LEASE

On an occasional farm in the central and northern part of the state, livestock, or livestock and machinery, are rented for cash with the farm. This happens when retired farmers leave their equipment on the farm for their sons, or for a former hired man, instead of selling them at auction. The best examples of leases of this kind were found in Calumet, Clark, Jackson and Buffalo counties. The personal property left on the farm is inventoried carefully at the beginning of the lease, and the tenant is required to return it at the end of the lease.

Following are the usual provisions covering the points of difference with ordinary cash leases:

"Said landlord hereby leases to said tenant his farm in .... described as follows: .... together with the personal property named in the accompanying inventory, which is hereby made a part of this lease."

"Said tenant hereby agrees to feed and properly care for the eight milk cows named in said inventory, to call in a veterinarian at once in case any of them are sick, and to notify said landlord at the same time, to pay all veterinary and breeding fees, and to return the same cows at the end of the lease, except such as have died, or have been sold by mutual agreement, in as good condition as the same are now in. The increase and products from said cows shall belong wholly to said tenant, as also the increase and products from any other livestock said tenant shall keep on said farm."

"Said tenant shall leave on the farm at the end of the lease the same amounts of the same kinds of feed as are found on the place at the beginning, the same being described in the attached inventory.

If machinery is furnished, it is provided for as follows:

"Said tenant shall have the use of all the tools and machinery now on said premises, and shall house and properly care for the same, and

repair them in case of breakage, and leave them upon said farm at the end of the lease in as good condition as the same now is, reasonable wear and use thereof only excepted."

In some cases, the tenant has only one-half the increase from the cattle. This enables the landlord to maintain his herd from year to year. In a few other cases, the tenant gets none of the increase, but still is expected to take care of the calves and young stock. The rent is of course adjusted accordingly. Feed must be left so that the landlord or the new tenant will have something for the cattle at the end of the lease.

The landlord seldom replaces machinery that wears out. Thus the providing of machinery is only a temporary arrangement on any farm. In the few cases where horses are furnished, the tenant pays horse-shoeing and veterinary bills.

This way of renting land is not to be encouraged. It too frequently results in trouble between landlord over the care of the livestock or the machinery, or over settling up the inventory at the end of the lease.

LEASE IV.—LANDLORD'S CATTLE DAIRY LEASE

Under Lease IV. in its regular form, the landlord furnishes the cattle and usually the hogs, sheep, and chickens, and the proceeds and increase are divided as in Lease II. In some counties, however, the tenant owns all the poultry and gets all the poultry receipts, and the landlord may in addition furnish the grass and clover seed and even the seed for field crops.

Figure 3 shows where this form of lease is found. It is giving ground to the half-and-half dairy lease in the south, and taking the place of grain leases in central and northern Wisconsin. It is ordinarily used under the following three circumstances:

1. Where land is not very valuable and tenants are scarce and do not have the means to furnish half of the cattle.
2. Where landlords are renting to members of the family.
3. Where landlords want to preserve purebred or high-producing herds intact.

The first circumstance accounts for its existence in northern and central Wisconsin; the other two for its existence in southern Wisconsin. This type of lease is also used in the Elgin dairy district of Illinois, partly because landlords need to maintain high-producing herds and partly because the intensive dairying practiced requires the tenants to furnish a great deal of labor for each acre and to buy a great deal of feed.

In the portions of Wisconsin where this lease is made, not only is the land less valuable and less productive, but it is more mixed in quality. The land which the landlord matches against the tenant's labor is a smaller share; the extra cattle which he provides in part makes

up the difference. Moreover, tenants are scarce and without means to buy livestock, for those who have means are able to start farming for themselves on the cheaper farms that abound everywhere. The dairying practiced in these sections is still new, and hence the leases are often crude and indefinite as to livestock details. And where this lease is found on family farms, the division of proceeds is not likely to be a very important matter.

Provisions for Owning Livestock

In all cases, the proceeds from the livestock and the increase are divided half and half, losses from accident or sickness due to the neglect of the tenant are replaced out of the tenant's share of the increase, and other losses are replaced out of undivided increase. The exact details of landlords' cattle leases, however, vary greatly as to what the landlord furnishes and how the increase is divided. The following are five general plans which are in use:

1. The landlord furnishes the parent stock only, and the tenant returns the identical animals in the same condition or as nearly as possible in the same condition as when he received them.

According to this plan, the tenant gets half the appreciation and the landlord stands all the depreciation of the parent stock from age.

2. The landlord furnishes both parent stock and young stock and the tenant returns the same animals as in No. 1 (above).

In this case, the tenant gets half the increase in the new-born animals, but the landlord has the appreciation on his young stock to offset the depreciation of his parent stock.

3. The landlord furnishes only parent stock and the tenant replaces out of the herd and undivided increase an equal number of cows of the same general age, weight and quality. Any stock sold is divided half and half.

In this case the depreciation of the parent stock is borne half and half.

4. The landlord furnishes both young and old stock and the tenant replaces out of the herd and undivided increase an equal number of animals of the same general age, weight and quality. Any stock sold is divided equally.

Both the appreciation of the young stock and the depreciation of the parent stock are shared in this case.

5. In a few cases, the tenant replaces any of the landlord's stock that is sold out of his half of the increase, the sales receipts being shared equally. The landlord's herd is thus kept at a constant number.

The tenant in this case stands all the depreciation on the parent stock.

It will be seen that plans No. 2 and 5 are least favorable to the tenant. In many cases, a tenant would do better furnishing half the cattle than under such an arrangement.

The increase of livestock under all of the foregoing plans is never divided till the end of the lease. If the tenant remains on a farm several years, unless cattle are constantly sold, he soon owns a considerable part of the producing herd. When he leaves the farm, he takes his increase to his next farm. If he has been farming under plans No. 1 or 2, he sometimes leaves the landlord a very small herd. If his new farm is a rented one, then he has part of a herd to put in with his new landlord's herd. Hence it is that leases of this kind are often irregular, tenant and landlord each furnishing whatever cattle they happen to own. The livestock furnished by the landlord is almost always inventoried, the cows by name, age, weight and description, and the young stock and sows by age and weight.

Hogs. The tenant owns half of the brood sows in about half the cases under this lease.

Taxes. In most cases the personal property taxes are shared equally; otherwise each party pays acccording to his interest, or the tenant pays all.

Feed. The departing tenant either leaves one-half the crop still unfed, or a definite quantity of feed. The landlord always wants to make sure there will be enough feed left to carry his livestock through to grass.

Horses and machinery. The landlord's cattle dairy lease is more likely to be irregular in the matter of horses and machinery than in any other particular. Either one or both of these are furnished in a quarter or a third of the leases. The reason for this is that retiring farmers who are leaving their cattle on the farm do not like to have an auction just to sell their horses and machinery. As with land-and-stock cash leases, they seldom replace horses and machinery as they wear out, the arrangement is only a temporary one. (See Lease III. for further details.)

Purebred cattle. Purebred cattle are easier to handle with Lease IV. than with the half-and-half dairy lease, because all that needs to be divided is the increase. The landlord is thus able to keep his original herd intact, and slowly build it up by adding one-half of the increase each year.

Letting purebred cattle out on shares. In recent years owners of purebred cattle have begun to let them out on shares to farmers near by. The tenant furnishes the feed, gets the milk and half of the young stock, the owner sometimes having first choice of the young stock.

Disadvantages of Lease IV. Landlords usually do not like furnishing cattle for the tenants. They complain that the cattle are not well handled and the herd soon runs down. Also, none of the arrangements for replacing the herd out of the increase works very accurately and definitely. For these two reasons, trouble frequently arises between landlord and tenant. The half-and-half-dairy lease is a better lease, because, with the cattle owned in common, each has an equal interest in the welfare of the herd.

Leass V.—The One-half-all-stock Lease.

Under this lease the landlord and tenant each furnish half of all the personal property on the farm. Leases of this kind are probably found in nearly every county of the state, but especially in sections where the half-and-half dairy lease is crowding out the landlord's cattle lease. The arrangement usually results when a retiring farmer sells a half of his farm equipment outright to a tenant. At the end of the lease, he either sells his remaining half of the machinery and horses to the departing tenant, or he buys the tenant out. Sometimes the tenant owns all the horses. The arrangement lasts long enough in some sections, in Crawford and Vernon Counties, for example, so that it becomes one of the regular leasing systems.

Lease VI.—The One-third Stock Lease.

Under this lease, the landlord furnishes all the livestock and machinery, and the tenant furnishes the labor and gets one-third of the proceeds. The expenses are usually divided in the same manner as the proceeds. Leases of this kind are found here and there all over the state, but especially in the central and northern counties. This is the place where would-be landlords with farms and equipment on their hands and would-be tenants with no capital are most likely to come together. The tenant does not always make laborer's wages. The plan would work better on a large well-stocked farm in southern Wisconsin, but here most tenants are able to furnish half of the livestock and get half the returns.

Grain-renting Systems.

Under a given lease, all that is divided is the crops. The small grain is divided at the threshing machine, the hay in the stack or mow, and the corn in the shock or in the crib. If any cows are kept, that is the tenant's business. He feeds them out of his share of the grain and gets all the proceeds.

Grain renting used to be the practice all over the state, and traces of it are still found in nearly every county. It began to pass away when dairying began to supplant wheat-growing. Even in a county as far south as Dodge, and on some regular stock farms, part of the grain is still sometimes divided at the machine. It is, of course, the usual method of dividing the proceeds from the small additional pieces of land that are everywhere rented on shares by neighboring farmers. Figure 3 shows where most of the grain renting is still found.

There are two types of grain leases in use in Wisconsin: the One-third Grain Lease and the One-half Grain Lease.

LEASE VII.—THE ONE-THIRD GRAIN LEASE.

This has recently become the commoner of the two grain leases. The landlord furnishes nothing but the farm, sometimes with buildings and a garden and sometimes not. The tenant furnishes horses, machinery, labor, seed and twine, pays the threshing bill, and hauls the grain to market. It is used everywhere by landlords who live a long way from their land or do not want to bother with looking after it. In central and northern Wisconsin there is a good deal of land which has thus been half abandoned by its owners. The rent they get is one-third of the small grain. The hay is usually divided equally, but the landlord has to pay for half the baling. Sometimes the corn is divided by halves in the field. If any grass or clover seed is sown, the landlord has to furnish it.

Potatoes. Probably over half the potatoes that are grown on shares in Wisconsin are grown according to the one-third lease. The tenant furnishes labor, tools, seed, and paris green, and puts the landlord's share of the potatoes in bags, boxes, or pits as the landlord directs, or he hauls them to market or to a warehouse at so much a load, say $1, or so much a bushel say from 2 to 5 cents. If hauled to a warehouse, the potatoes are divided by weight when sold.

LEASE VIII.—THE ONE-HALF GRAIN LEASE.

This lease is like Lease VII. except that the landlord furnishes half the seed, usually half the twine, pays for half the threshing bill, and gets one half the grain and hay. This lease is found mostly in the old grain-growing counties where grain-growing still persists, namely, Jackson, Eau Claire, Dunn, Buffalo, Pepin, Pierce and St. Croix Counties; but is also frequently found both north and south in such counties as Columbus, Sauk, Vernon, Burnett, Barron, Rusk and Marinette. Many potatoes are grown under this lease in Waupaca and Waushara Counties and farther north. Each pays for half the paris green. The tenant still gets his pay for hauling.

Tobacco. A large amount of tobacco is grown under Lease VIII, especially in Dane, Vernon, Crawford and Rock Counties. The landlord in this case, however, furnishes nearly everything—land, sheds, tools and machinery, horses, fertilizer. The tenant performs all the labor from the planting of the seed to the delivery of the crop to market. Each pays half of the expenses for twine, wrapping paper, seed, and so forth. The proceeds are shared equally. The tenant frequently lives with the landlord during the tobacco season, paying board at a nominal rate and working for the landlord at a nominal wage. In Vernon County, for example, tenants were paying $5 an acre, or $35 for the season, for board for themselves and all the extra help hired at harvesting, but they were working for the landlord at haying and grain harvesting at $1 a day (1916). If the tenant is married, he may have free house rent and garden for his family.

Mixed Grain-and-dairy Renting.

As one would expect, where grain farming is gradually giving place to dairy farming, grain and dairy leases shade into each other gradually. However, two general types of mixed leases can be pointed out, the "Share-cash Lease" and what is here called the "Grain-and-dairy Lease."

Lease IX.—The Share-Cash Lease.

The 1910 census counted 658 share-cash leases in Wisconsin, but most of these are not the genuine sort. The true share-cash lease is found best in Pierce and St. Croix Counties. Grain is divided either one-half or one-third, usually the former, and the tenant owns all the cattle, pays cash rent for the pasture, feeds his share of the grain, and has all the proceeds. The pasture rents used to be low, but they are now \$3 to \$4 an acre, or \$5 to \$8 a head in some cases. In many cases the tenants also pay cash rent for corn land now. Some of these farms have silos.

Lease X.—The Grain-and-dairy Lease.

In Eau Claire County, for example, are many leases which are made out almost exactly like either half-and-half or landlord's cattle dairy leases. The landlord furnishes either half or all of the cattle, and the milk receipts are divided half and half. Upon examining the farm receipts, however, one discovers the real nature of the case. There may be only 6 milk cows on a 200-acre farm. The big income is from the grain, which is still divided at the machine.

This kind of tenant farming in varying degrees of grain-growing and dairying prevails all the way from Burnett to Crawford Counties on the west, and from Waupaca to Green Lake on the east. It is characteristic of Waupaca County, where potatoes and dairying are mixed. Much tobacco is grown in Dane and Crawford Counties on farms where dairying is merely an adjunct to it. In fact, most of the half-and-half dairy leases from Sauk County northward involve more grain than they do dairying.

Additional Rented Land.

The 1910 census showed 681,000 acres, or one-sixth of all the rented land in the state, being farmed by neighboring farmers as an addition to their farms. Probably over half of this land is rented for cash. Another part is hay land cut on shares. The rest is farmed on the one-half or the one-third grain renting plan. Needless to say, little manure is ever put on land rented in this way. The largest acreages of this land are found in central and northern Wisconsin. It is usually owned by absentee owners and speculators. Much of it is in tracts

too small to support a family. The least that the owners can rightly do with it is to rent it for a term of years and require the tenants to haul a fair proportion of the farm manure onto the rented portions of their farms.

FIG. 3. DIFFERENT TYPES OF SHARE LEASING.

The half-and half dairy lease is the predominating type in the south central part of the state; the landlord's cattle lease and grain leases are found principally in the central and western portions.

THE AGREEMENT TO WORK LAND.

All the leases discussed up to this point have been actual farm leases. As a matter of fact, the form of the share lease which most lawyers use in making out contracts between landlords and tenants is not a lease at all, but simply an "agreement to work land." Under this arrangement the landlord is always called "the party of the first

part" and never the "landlord" or "lessor," and the tenant is called the "party of the second part." The party of the second part never owns his crops or his livestock till after they are marketed or divided. He is in effect a hired man who, in return for faithfully carrying out the conditions of the agreement, receives from the party of the first part a half or a third or two-thirds of the proceeds and the increase. Lawyers use this form of lease because the legal forms are printed this way, but more particularly because it is a simple way of securing to the owner his share of the proceeds. If the tenant never owns the crops until they are marketed, he cannot dispose of them without the owner's consent, and no one else can attach them. It is a way of escaping the difficulty arising from the fact that Wisconsin has no crop-lien law.

Following is the form for an agreement to work land:

> THIS AGREEMENT, Made the .... day of .... 19...., between .... of ...., ... County, State of Wisconsin, party of the first part, and .... of the same County and State, party of the second part,
>
> WITNESSETH, That whereas said party of the first part is the owner of the following described premises, to wit: .... the said party of the second part hereby agrees to work said premises for the said party of the first part for the term of .... year, dating from .... 19...., upon the following conditions, namely,
>
> THAT said party of the first part shall furnish ....
>
> THAT said party of the second part shall furnish ......
>
> The two parties shall jointly furnish ....
>
> Said party of the second part further agrees ....
>
> In return for the full and faithful performance of this agreement by the party of the second part, said party of the first part hereby agrees to pay said party of the first part one-half the ....
>
> The said premises remain in the possession of the party of the first part, except the buildings and garden, and these are to be surrendered peacefully and quietly at the end of the lease.
>
> WITNESS our hands the date above written, etc.

These agreements to work land are made to contain all the usual provisions of the several kinds of leases for which they are substituted. They also usually contain right of entrance clauses, breach of contract clauses and all the other legal provisions of share leases.

Cash vs. Share Renting

The actual reasons given by landlords and tenants in different parts of the state for preferring cash or share leases are as follows:

I. REASONS FOR PREFERRING SHARE RENT.

A. *Landlord's reasons*:

1. Cash rents are never high enough. Share leases bring the landlord a larger profit.
2. The landlord is able under a share lease to help manage the farm and make it yield a larger income for both him and the tenant than if the tenant managed it alone.
3. The landlord who has a good herd of cattle is able to leave all or part of it on the farm, where it will yield both landlord and tenant a larger profit than the poorer herd which a tenant will bring onto the farm.
4. The landlord is able to look after his farm at share rent and keep a tenant from "skinning the land." Cash tenants feel they have a right to do as they please so long as they pay the rent.
5. Cash tenants do not usually put as much stock on farms as share tenants, especially under half-and-half dairy leases, where the landlord furnishes half the cattle.
6. Cash tenants will not bid as high as they should for land for fear of losing all on a poor crop. This is especially true on farms with light soils.
7. On poor years, tenants cannot make their rent and the landlord loses part of it; but in good years the tenant always gets the full surplus of the big crop.

B. *Tenant's reasons:*

1. Tenants who have not enough money prefer share renting because it requires less capital. In fact, many of them could not possibly rent any other way.
2. Tenants wanting to build up a herd of cattle like to rent a farm with a good herd on shares and get half the increase.
3. Landlords renting on shares are more willing to make improvements because they get a share in the increased product right from the start, while at cash rent they have to wait till they can raise the rent.
4. Some tenants, especially at grain farming, are glad to share the risk of loss with the landlord.

II REASONS FOR PREFERRING CASH LEASES.

A. *Landlord's reasons*:

1. Cash renting is less bother—landlords do not have to look after managing their farms and getting their share of the increase and of the products sold.
2. Much trouble and friction is saved between landlord and tenant over managing the farm work, selling the farm produce, and dividing the receipts and expenses.
3. Landlords do not have to worry over whether their tenants are stealing from them or beating them out of their share of the farm income.
4. Poor slipshod tenant farmers should stand the consequences of their own farming. The best way to rent to such a farmer is for cash rent.

5. In some sections of the state, tenants lack ambition. At share rent they are sure of a living anyway, since they get a large part of it from the farm, and they do not worry much about the regular field crops. As a result the landlord gets a poor return from his land.
6. Landlords know in advance what they are going to get.
7. Bargains can be made more easily and more accurately in cash terms than in share terms. For example, in some sections landlords cannot afford to give tenants half of all the increase and sales of produce and yet the custom of the neighborhood makes it impossible for them to rent for any other share than one-half. Accordingly they rent for cash.

B. *Tenant's reasons:*
1. Most tenants prefer to be their own bosses more than they can be under share leases. As a class they do not have as high an opinion of the advice and direction of their landlord as do the landlords themselves, in many cases to their own sorrow and loss.
2. There is too much danger of friction and trouble with landlords at share rents. Many landlords are suspicious and meddlesome. Share leases offer so many chances for trouble.
3. Many tenants want to be free to engage in enterprises entirely of their own, such as buying and selling livestock, feeding sheep or cattle, growing sugar beets, threshing, silo-filling, and get all the profits themselves
4. Tenants frequently say that they are "not going to make slaves of themselves and give their landlords half." They forget that cash rent has to come out of their labor also, and it may be a bigger share than the one-half in some cases. Their opinion has this much foundation, however, that after they have done a certain amount of work, any extra effort they put forth pays the landlords better than it does them.
5. Tenants generally believe that cash leases pay better than share leases at present rents and prices.
6. Most tenants want to keep their increasing capital in the form of livestock and equipment. When their herds get large, they want to rent a farm for cash and furnish all the livestock.
7. More accurate bargains can be made in cash terms.

Cash vs. Share-rent Farming.

No reliable figures are available to show the actual results of cash-rent and share-rent farming. The popular impression in the share-renting sections of the Rock River Valley is that cash-rent farming is the poorer, and in the cash-renting sections of western Wisconsin, that share-rent farming is the poorer. The only census figures on this point are for the year 1900. These show that cash-rented farms average 15 acres less a farm, carry about one-fifth more buildings, livestock and hired labor an acre, and yield about one-fifth more crop products an acre. Table I. compares cash and share-renting on 193 farms in 1914, 1915 and 1916 in eight counties in Wisconsin, as follows: Walworth, Green, Dane, Winnebago, Wood, Eau Claire,

St. Croix and Barron. The share-renting on these farms was mostly under half-and-half dairy leases. This accounts for their large equipment. Labor and current expenses are larger on the cash-rented farms, just as they were according to the 1900 census.

These figures seem to indicate that share-rent farmers make their money by farming extensively, using machinery, and keeping expenses down. The usual explanation offered for this is that share tenants figure that they lose by hiring more than a certain amount of labor, because they have to pay all the bills and the landlord gets half the returns. In any one neighborhood, this does not seem to be strikingly true. The supervision of landlords, the restrictions of leases, and the force of custom, keep share tenants farming about like owners. The theory works itself out, however, in the choice of a lease for farms of different sizes, and as between types of farming and different sections of the state.

TABLE I. CASH-RENT COMPARED WITH SHARE-RENT FARMING
193 Farms in 8 counties of Wisconsin, 1914-16.

	Cash	Share
Acres a farm	152	191
Value an acre	$91	$112
Value of farm	$14,800	$21,400
Value of equipment	$2,790	$4,570
Value tenant's equipment	$2,790	$2,670
Value landlord's equipment	none	$1,900
Gross receipts[1]	$1,893	$2,815
Expenses and depreciaton	$935	$1,091
Net farm income	$958	$1,724
Man labor[2]	$318	$323
Expenses per $100 farm value	$6.30	$5.10
Man labor per $100 farm value	$2.15	$1.51

[1] Includes increase in inventory.
[2] In addition to the farmer's own labor.

Cash renting always predominates where farms are small, or cheap; a share tenant cannot make a living from a half-share of the income from a small or a cheap farm. Cash renting also leads in the small truck farming districts near large cities, one reason for this being that income from such farming is hard to divide into shares. This accounts for the high prevalance of cash tenancy in northern and eastern Wisconsin. (See Figure 2.) Cash renting prevails in south-western Wisconsin largely because a half-share of the income from the grazing

type of farming practiced in these counties is too good a lay-out for the tenant. The only explanation for cash-renting in La Crosse and southern Trempealeau and Buffalo Counties is the existence here of a German family system under which the parents help their sons buy dairy herds so that they can start for themselves as cash tenants.

In the Rock River Valley dairy section, fewer prospective tenants have the capital or the family support needed to start as cash tenants. Share tenancy is therefore the first step up the ladder. The only other sections where share-renting takes the lead are the grain-farming counties of northwestern Wisconsin, such as Pierce, St. Croix, Dunn, Eau Claire and Jackson Counties, and the potato and the tobacco counties, such as Vernon, Dane, Portage, Waushara, Waupaca and Marquette Counties.

Three classes of landlords generally rent for cash or grain rent, namely, women, speculators, and absentee landlords (landlords living a long way from their farms). Such people are not able to look after their farms, or do not want to bother with them. Retired farmers, on the other hand, usually prefer to rent under land-and-stock share leases, except in southwestern Wisconsin and in La Crosse County. Tenants in grain-farming regions usually object to land-and-stock dairy leases because it increases the amount of labor which they have to furnish.

Undoubtedly, more trouble results between landlords and tenants under land-and-stock share leases than under cash leases. For this reason, one-half of the share leases examined in Dane, Jefferson, Rock and Walworth Counties were year-to-year leases, and only one-sixth were five-year leases, whereas only 30 per cent of the cash leases were for one year, and 31 per cent were for five years.

Cash-rent farming can undoubtedly be as successful as share-rent farming, if the cash-renting landlords will put proper restrictions in their leases, choose their tenants carefully, and then give them proper supervision. In those sections of Wisconsin where cash-renting results in poor agriculture, it is largely because the landlords are poor landlords. Where share-renting is resulting in poor agriculture, very often it is because of poor tenants—all the good farmers can easily obtain farms of their own.

Division of Farm Income Under Cash Rent.

Table II. shows the landlord's returns from two groups of farms, 1185 and 45 resepectively, recently rented for cash rent in Wisconsin. The data from the 1185 farms were obtained from letters written in July, 1917, to landlords and tenants in all the counties in the state. The data as to the 45 farms were obtained from surveys of these farms made in cooperation with the United States Department of Agriculture in 1914, 1915 and 1916 in four counties, namely, Dane, Walworth, Barron and St. Croix.

The results in the two columns are quite similar.

TABLE II. RETURNS TO LANDLORDS FROM CASH RENT IN WISCONSIN 1914-1917

	1185 Farms	45 Farms
Acres a farm	145	152
Value an acre	$99	$97
Value of real estate on farm	$14,375	$14,800
Rent per farm	$565	$570
Rent per acre	$3.89	$3.75
Total expenses of landlord	$142	$137
Taxes and insurance	$109	$111
Upkeep of real estate	$26	$22
Grass and clover seed	$7	$4
Balance in favor of landlord	$423	$409
Depreciation on farm buildings	$72	$65
Landlord's net income	$351	368
Per cent of real estate value—rent	3.94	3.85
" " " " " " —total expenses	.99	.93
" " " " " " —taxes and insurance	.76	.75
" " " " " " —upkeep of real estate	.18	.15
" " " " " " —seeds	.05	.03
" " " " " " —landlord's balance	2.95	2.92
" " " " " " —depreciation	.50	.44
" " " " " " —landlord's net income	2.45	2.48

The figures show that cash rents average slightly less than 4 per cent of the market value of the farm. The cash actually paid out by the landlord in taxes, insurance, repairs of buildings and fences, and grass seed, amounts to practically 1 per cent of the value of the farm, leaving the landlord a cash balance of about 3 per cent. Out of this 3 per cent, an additional ½ per cent should be deducted for depreciation of farm buildings. In figuring his net income, a farmer should subtract enough from each year's receipts so that when his buildings are finally worn out, he will have enough set aside to construct new buildings as good as the old ones were when new. This charge is, of course, in addition to repairs and maintenance. About 2½ per cent seems to be the actual returns to cash-renting landlords in Wisconsin, if returns are figured on the basis of the market value of their real estate. However, if returns are figured on the basis of original investment, that is, the amount paid for the farm plus the

amounts spent upon the farm from time to time for additional improvements, they will be much higher than 2½ per cent, especially when land values are rising rapidly as at present. A 2½ per cent on the market value of an average farm in Wisconsin in 1915 is equal to a 3.8 per cent return on the amount paid for the same farm in 1905, and probably 2½ per cent on the 1920 valuation would equal from 4 to 5 per cent on the values of 1910.

The tenant's share at cash rent. Table III. shows how the income of 45 cash-rented farms was divided between landlord and tenant.

TABLE III. DIVISION OF INCOME OF 45 CASH-RENTED FARMS IN WISCONSIN—1914-16*

	Farm	Landlord	Tenant
Investment...	$17,590	$14,800	$2,790
Gross receipts	1,893	570	1,323
Current expenses	823	137	686
Depreciation	112	65	47
Net income	958	368	590

The tenant matches his own labor and management, his $2,790 of equipment, $686 of current expenses, and $47 of depreciation on his machinery, against the landlord's $14,800 farm, $137 of cash outlay for taxes, seeds and the like, and $65 of depreciation, and gets as a return $590, or 62 per cent of the net farm income, this income including increase in livestock and crops, but not in land values. To this $590 should be added the value of the house rent, fuel, meat, and so forth, which the tenant's family receives from the farm, worth probably $400 in 1914–15. From this total of $990 should be subtracted $155 of interest on the tenant's working capital (at 5.6 per cent),** leaving a balance of $835. This sum covers both his wages for labor and wages for management. If the tenant's labor at hired men's rates was worth $475, his profits or wages of management would be $360. The landlord's net income, according to Table II, was 2.48 per cent on the market value of this farm, or 3.8 per cent return on the original investment if made 10 years previously.

Why landlords' returns are low. The reason that landlords' returns are low is that enough landlords are willing to become landlords at these low returns to supply prospective tenants with all the land to rent they want at these figures. If the rents were higher, more young

* This table shows division of income satisfactorily but not total incomes. The farms are poorer than the average cash-rented farms of the state.

** See Wis. Exp. Sta. Bul. 247.

men would buy instead of renting. Tenants prefer owning to renting principally for the very same reason that landlords want to own land —both are figuring on the rise in the value of land. The bidding between these two parties sets the rents where they are. The value of farm lands and buildings rose over 3 per cent a year in Wisonsin between 1905 and 1915. Landlords have no reason to expect rents on farm lands to pay them the usual rates of interest on other investments. The market value of land represents two things, present earning power, and anticipated increase in earning power. Normal rates of interest can be expected only on present earning power. From one-fifth to two-fifths of the market price of all land in Wisconsin represents anticipated increase in earning power, expressed in higher future land values.

Other reasons why landlords' returns are low are as follows: (1) Farm land has usually been considered a safe investment in Wisconsin, especially by the landlord class, which is largely made up of retired farmers. (2) Speculation in land lowers returns by putting more farms on the market for rent and also by raising the price of land by making buyers overestimate both its present and its future earning power. (3) Rents always advance somewhat more slowly than prices of farm products and in ordinary times more slowly than land values. (When prices of farm products rise sharply, as during the war period, rents will usually rise ahead of land values. In fact, rents may rise and fall again and land values not be affected.) Theoretically, land values are supposed to depend upon rents, but actually, in a country where only a small part of the land is rented, rents are usually fixed at the customary rate, or at a nominal increase upon it, or with reference to the market value of the farm as determined by comparison with similar farms in the same neighborhood. (4) Taxes are recently much higher in Wisconsin than formerly. Landlords have not yet been able to raise rents enough to compensate for the higher taxes. Rents always lag behind taxes. (5) Cash tenants often have too little equipment for profitable farming. Hence they can safely offer only a low rent.

Cash rents in different parts of the state. Cash rents by the acre vary only in a general way with the market prices of land. Table IV compares, for eight different sections of Wisconsin, the cash rents an acre in 1916–17 with the market value of rented land and rate of return upon market value. Cash rents are high relative to land values wherever prevailing interest rates are relatively high, as in northern Wisconsin; where landlords furnish all grass and clover seed; and wherever share renting predominates, as in the Rock River Valley. Cash rents are relatively low where interest rates are low, as in eastern Wisconsin; where speculation is unusually active; where tenants are unusually poor farmers; where frequent crop failures increase the risks of farming; and near large cities where land is relatively overvalued with respect to production.

TABLE IV. COMPARISON OF RENTS, LAND VALUES AND RATE OF RETURN FOR 1155 FARMS IN 8 SECTIONS OF WISCONSIN.

	Value of rented land an acre	Cash rents an acre	Per cent cash rent of value
Eastern—Lake Shore	$115.00	$4.36	3.79
Rock River Valley	115.00	4.67	4.06
Southwestern Upland	118.50	4.71	3.98
Central Western	74.60	2.74	3.66
Central Sandy Plain	60.10	2.22	3.69
Northwestern—Grain Section	75.60	3.20	4.23
Semi-settled Section	70.30	2.94	4.18
Extreme Northern	45.70	1.92	4.22
State	99.00	3.89	3.94

DIVISION OF FARM INCOME AT SHARE RENT

Following is a series of tables which analyze the farm business of a large number of farms rented under the various types of share leases used in Wisconsin. The method of analysis will appear from the tables. All the items are given for the farm enterprise as a whole, and for landlord and tenant separately. The total investment is divided into investment in real estate and in equipment. Likewise the gross receipts are divided into cash receipts and increase in inventory. From the gross receipts, the cash expenses and the depreciation charges are subtracted. The remainder, called *net income,* is the amount of actual increase upon the original investment. From net income is subtracted the wages of the tenant for his actual labor at the going wage for hired men, interest on the landlord's investment in real estate at the going rate for investments in land, and interest at the market rate for long-time loans for landlord's and tenant's investments in equipment and livestock. The remainder is profits, or wages of management.

The man-labor charged as expense consists of hired labor and family labor, the hired labor at actual wages paid plus the estimated cost of the board insofar as not furnished by the farm (approximately $8 a month), and the family labor at its estimated hired labor equivalent. The farmer's wage as his own hired man was taken from Wisconsin Bulletin 316, "Farm Labor in Wisconsin."* Interest on equipment and livestock is based on Wisconsin Bulletin 247, "Farm Credit in Wisconsin." Interest on investment in land was based on Tables I. and IV.

* This method of computing the wages of the farmer and his family is not very accurate.

It is assumed that the net return which landlords are willing to take upon land at cash rent is a proper rate to use as the market rate for investment in land. This is a true market rate based upon the bids of a very large number of landlords and tenants, each bidding in full recognition of the possible alternative uses of their capital, management and labor. Under share rent, the landlord assumes greatly increased burdens of management and responsibility. Under cash rent, he assumes very light burdens of responsibility. The surplus a landlord gets at share rent over what he could get at cash rent is, therefore, properly considered profits or wages of management.

TABLE V. SUMMARY OF THE BUSINESS OF 66 FARMS IN GREEN COUNTY, WISCONSIN, OPERATED UNDER HALF-AND-HALF DAIRY LEASES.

	Farm	Landlord	Tenant
Number of acres		210	
Value per acre		$120	
Investment	$30,586	$27,439	$3,147
Real estate	$25,200	$25,200	....
Equipment	5,386	2,239	$3,147
Gross receipts	3,110	1,526	1,584
Cash receipts	2,140	1,042	1,098
Increase in inventory	970	484	486
Cost charges	1,265	537	758
Cash expenses	1,070	405	665
Man labor[1]	481	5	476
Taxes and insurance	234	211	23
Upkeep	64	45	19
Other cash expenses	291	144	147
Depreciation on real estate	132	132	....
Depreciation on equipment	63	....	63
Net income	1,845	989	856
Additional cost charges	1,483	788	695
Interest on real estate[1]	655	655	....
" " equipment[2]	320	133	187
Farmer's wages[3]	508	....	508
Profits	362	201	161

[1]At 2.6 per cent, the cash-rent return, minus taxes and other expenses. See Tables I. and IV.

[2]At 5.95 per cent. See Bul. 247, Wis. Agr. Exp. Sta.

[3]At $408, plus $100 for the part of the farmer's board which is not furnished by the farm.

TABLE VI. SUMMARY OF THE BUSINESS OF 50 FARMS IN DANE AND WALWORTH COUNTIES OPERATED UNDER HALF-AND-HALF DAIRY LEASES.

	Farm	Landlord	Tenant
Number of acres		163	
Value per acre		$111	
Investment	$21,719	$19,396	$2,323
Real estate	$18,156	$18,156	....
Equipment	3,563	1,240	2,323
Gross receipts	2,665	1,282	1,383
Cash receipts	2,164	1,037	1,127
Increase in inventory	501	245	256
Cost charges	1,058	403	655
Cash expenses	945	327	618
Man labor	394	3	391
Taxes and insurance	167	145	22
Upkeep	77	53	24
Other cash expenses	307	126	181
Depreciation on real estate	76	76	....
Depreciation on equipment	37	....	37
Net income	1,607	879	728
Additional cost charges	1,133	531	602
Interest on real estate[1]	468	468	....
" on equipment[2]	181	63	118
Farmer's wages[3]	484	....	484
Profits	474	348	126

(1) At 2.58 per cent. (2) At 5.1 per cent. (3) At $384 plus $100.

The 66 farms reported in Table V. are large dairy farms. They average 27 milk cows a farm; 76 per cent of the gross receipts are from cattle, and 19 per cent from hogs. The farms in Table VI. are smaller and not so exclusively given to dairying. The gross receipts are smaller, but larger in proportion to the size of the farms. Table VII. combines the reports of 10 farms in central and northern Wisconsin operated under landlord's cattle dairy leases. This lease is generally used in the newer sections where tenants are scarce and land is not so valuable. The 10 farms average 120 acres in size and are worth only $82 per acre. This makes a real estate investment of $10,840 as compared with $27,439 and $19,396 in the first two tables. The landlords furnish the milk cows, brood sows, and usually half the poultry. The young stock is divided half and half. The landlord usually stands the depreciation on the parent stock.

TABLE VII. SUMMARY OF THE BUSINESS OF 10 FARMS OPERATED UNDER LANDLORD'S CATTLE DAIRY LEASES.

	Farm	Landlord	Tenant
Number of acres		120	
Value per acre		$82	
Investment	$11,595	$10,840	$755
Real Estate	$9,850	$9,850	....
Equipment	1,745	990	$755
Gross receipts	1,502	714	788
Cash receipts	1,126	$563	$563
Increase in inventory	376	151	225
Cost charges	549	224	325
Cash expenses	462	169	293
Man labor	176	....	176
Taxes and insurance	76	71	5
Upkeep	38	18	20
Other cash expenses	172	80	92
Depreciation on real estate	55	55	....
" " equipment	32	....	32
Net income	953	490	463
Additional cost charges	925	431	494
Interest on real estate[1]	369	369	....
" " equipment.[2]	108	62	46
Farmer's wages	448	....	448
Profits	28	59	-31

(1) At 3.4 per cent. (2) At 6.17 per cent.

Table VIII. combines the reports of several farms in the grain section in northwestern Wisconsin farmed under the one third arrangement. As will be seen, the tenant furnishes all the equipment, all the cash expenses except taxes, upkeep of real estate, grass seed, and part of the twine and threshing, and gets two-thirds the grain, usually half the hay, and all the livestock receipts. The tenant of course feeds his own share of hay and grain to his livestock. The tenants reported in the table paid an average of $27 cash rent in addition for pasture for their livestock.

TABLE VIII. ANALYSIS OF BUSINESS OF FARMS OPERATED UNDER ONE-THIRD GRAIN LEASES.

	Farm	Landlord	Tenant
Number of acres		193	
Value per acre		$82	
Investment	$17,839	$16,187	$1,652
Real estate	$16,133	$16,133	....
Equipment	1,706	54	$1,652
Gross receipts	1,946	739	1,207
Cash receipts	1,726	723	1,003
Increase in inventory	220	16	204
Cost charges	845	214	631
Cash expenses	782	183	599
Man labor	341	....	341
Taxes and insurance	132	113	19
Upkeep	38	22	16
Other cash expenses	271	48	223
Depreciation on real estate	31	31	....
Depreciation on equipment	32	....	32
Net income	1,101	525	576
Additional cost charges	1,068	509	559
Interest on real estate[1]	506	506	....
" on equipment[2]	102	3	99
Farmer's wages	460	....	460
Profits	33	16	17

(1) At 3.08 per cent. (2) At 6 per cent.

Table IX. analyzes mixed grain and dairy leases. These leases are used in sections of the state where grain farming is giving place to dairy farming. In its provisions, the lease used is much like a half-and-half dairy lease. In actual fact, it is quite different, because although the landlord furnishes half the milk cows and sows, only a few are kept. Most of the grain is sold. The 284-acre farms reported in Table IX. average only 8 cows per farm. Thus the tenants furnish the major part of the equipment. The tenants in addition must feed their work horses out of their half of the grain and pay the usual expenses under one-half grain leases.

TABLE IX. ANALYSIS OF THE BUSINESS OF FARMS OPERATED UNDER MIXED GRAIN AND DAIRY LEASES.

	Farm	Landlord	Tenant
Number of acres		284	
Value per acre		$70	
Investment	$23,206	$20,692	$2,514
Real estate	$19,950	$19,950	......
Equipment	3,256	742	$2,514
Gross receipts	2,729	1,427	1,302
Cash receipts	2,278	1,209	1,069
Increase in inventory	454	221	233
Cost charge	1,084	395	689
Cash expenses	902	277	625
Man labor	368	....	368
Taxes and insurance	188	160	28
Upkeep	55	24	31
Other cash expenses	291	93	198
Depreciation on real estate	118	118	....
Depreciation on equipment	64	....	64
Net income	1,645	1,032	613
Additional cost charges	1,232	622	610
Interest on real estate[1]	578	578	....
Interest on equipment[2]	194	44	150
Farmer's wages	460	....	460
Profits	416	413	3

(1) At 2.9 per cent. (2) At 6 per cent.

Table X. summarizes the six sets of farm records. The share of the total investment furnished by the tenant is nearly twice as much under cash leases as under the share leases. The reason that the landlord's share is larger in Table V. than in Table VII. is that his land in the former table is relatively overvalued. The cheapness of the land explains the largeness of the tenant's share under the mixed grain and dairy leases. Increase in inventory on horses sometimes gives half-and-half tenants slightly more than half the gross receipts. Feeding horses out of divided grain reduces the tenant's share under grain and mixed grain and dairy leases. The labor and other expenses of the tenants usually exceed the taxes, insurance and other expenses of the landlord sufficiently to reduce their net incomes to several per cent under half. The 45 per cent in Dane and Walworth Counties results because the tenants were paying a larger part than in Green County of the expenses for seeds, twine, threshing, fuel and oil, milk-hauling

Table X. Comparison of Tenant's Investment, Expenditures, Income and Profits Under Various Leases.

Kinds of leases	Share of Tenant—Per cent				
	Invest-ment	Gross receipts	Net income	Cost[1] charges	Total[2] profit
Cash	16	70	62	70	100
Half-and-half dairy (Green County)	9	51	47	53	74
Half-and-half dairy (Dane and Walworth)	11	52	45	58	60
Landlord's cattle	6	53	49	55	86
Two-thirds grain	9	62	52	62	96
Mixed grain and dairy	11	48	37	56	51

(1) Cash expenses, depreciation, interest on investment and wages of farmer. (Cost of management is not included.)
(2) Living from the farm, estimated at $400, is added to the tenants's profits.

and the like. The 37 per cent under the mixed grain and dairy leases resulted because tenant's labor expenses were relatively high and landlord's taxes low. In both these cases, tenants apparently were hiring too much labor for their own best interests.

When landlord's interest and tenant's own labor and interest are added to current expenses to give total cost charges, not including wages of management, the tenant is found to be contributing much more than half in all the different half-share leases, but less than two-thirds in the one-third leases. Tenant's net incomes are always a much smaller proportion of the total than their cost charges. These come nearest to being in the same proportion in Green County and under the landlord's cattle leases. Green County farming is extensive summer-season pasture dairying. The disproportion is most in Dane and Walworth Counties where the farming is more intensive, and under the mixed grain and dairy leases. The tenant's share of total profits* is most where his share of the total cost charges is low relative to proportion of net income. The landlord receives very little profit under the two-thirds grain lease where he contributes practically nothing but the land. It is greater where he contributes working capital and management, as under the half-and-half dairy lease. The landlord's cattle leases bring poor returns to both landlord and tenant.

If the reports from the farms worked under the different land-and-stock share leases are roughly combined, the landlords seem to be getting what they would from cash rent, plus interest on livestock investment, plus about $250 as profits, or pay for management. The

* Total profits include the value of the living which the tenant gets from the farm, in the form of rent, fuel, potatoes, milk and the like. This has been omitted from Tables 6, 7, 8, 9 and 10. Bulletin 635 of the U. S. Dept. of Agriculture, called "What the Farm Contributes to the Farmer's Living," reckoned the value of this living in 1914 at $375 for Wisconsin families averaging 4.2 persons, including hired help. Prices have risen since 1914. But tenant families are often small. And tenant houses are very often worth less than average rent. In many cases fuel is not furnished as part of the living. Whatever the tenant's living from the farm is worth, this amount should be added to his share of "Profits." The figure $400 has been used in these tables.

tenants seem to be getting wages as hired men, amounting to $475, plus a profit consisting of a partial living from the farm for their families, estimated to be worth $400, and about $125 in addition. This is $165 more than the $360, the wages of management of the 45 cash tenants as shown in the discussion following Table III. These 45 farms, however, are far poorer than the average cash-rented farms. Of the total farm profits under share rent, the tenants are getting 68 per cent and the landlords 32 per cent. This is probably about in proportion to the burden of management and responsibility which each assumes. The range in profits on the share-rented farms studied was all the way from $1,100 loss to $2,500 profit. Most of the very large profits were due to the landlord's herd of cattle and his judgment in buying and selling and planning the work. But the major part of all the usual profits were undoubtedly due to the tenant's judgment and especially his skill in caring for the crops and livestock and managing the work from day to day. Under share leases, each gets the benefits of the other's good management. Obviously the tenant loses by this whenever he is a better manager than his landlord, and he gains by it when he is a poorer manager.

DIVIDING THE EXPENSES

There are two theories which farmers advance as to how the different expenses should be divided under share rent. One theory is that the only safe and proper way is to find out what is the custom in the neighborhood and follow it. The other theory is that the expenses should be arranged to suit the particular parties and the farm to be worked, the ideal being that the expenses are divided in the same proportion as the income.

The usual justification for the first theory is that the prevailing terms of share leases represent market valuations the same as cash rentals, wages, and prices of farm products, that these terms are determined in fair competition between landlord and tenant on the basis of supply and demand and therefore represent justice between them. It is true that farms vary greatly in quality, but so do tenant farmers. If the good tenants get the good farms, as is likely to be the case, and the poor tenants the poor farms, then justice is achieved even in such cases. The landlord is making a poor land contribution, but the tenant is making a poor management contribution. Another argument advanced in favor of this method is that it protects both parties, saves them from being taken advantage of by the other party when that party has the whip hand. If either party allows the other to deviate from the custom, there is no telling where it will stop. Also, when there is a standard recognized way of handling farm expenses, every one knows about it and there are fewer misunderstandings.

The arguments against always following the custom of the neighborhood are as follows: (1) Competition does not in actual practice make proper adjustment for differences among farms, landlords and

tenants. Farms vary greatly in fertility, improvements, and location. In any one locality, on some farms the crops to be grown are largely of the labor-consuming kind, like corn; on others, they are mostly hay and small grain. The cattle furnished by landlords and tenants vary greatly in quality. Since both landlord and tenant contribute to management, the relative efficiency of the two is a matter of great importance. It is highly improbable that competition can make adjustment for all these differences by getting the right tenant on the right farm. (2) Customary arrangements do not adapt themselves rapidly enough to changing conditions, such as changing land values, wages, types of farming. In times like the present, this is a matter of great concern.

The difficulty with the second theory is that it is extremely hard to apply it even in a general way, because it is impossible accurately to calculate many of the contributions of the two parties, such as the rent of the land, the value of the farmer's own labor, the value of the family labor used on the farm, and above all, the value of the management contributed by landlord and tenant. Also, it is hard to calculate the value of the house-rent and supplies the tenant receives from the farm.

The general basis of value for all these contributions is their prevailing market prices. For the landlord's land, this will be what it will rent for at cash rent. For the farmer's own labor this will be something less than what he could hire out for as a plain hired man, plus an allowance for that part of his board which is not furnished out of farm supplies. The often-suggested plan of figuring the value of the labor of other members of the family on the farm at what it could hire out for is not sound. Any amount of family labor is willing to work at all sorts of tasks on owner-operated farms at far less than it would hire out for away from home, and it is not fair to treat family labor on rented farms on any different basis. And where can one go to get the market value of the management contributed by the landlord and tenant on a share-rented farm? The method used on owner-farms is to allow for all the other expenses and call the rest wages of management. The method has not been properly used, however; some of the expenses have usually been figured so high that nothing has been left for management. The rents charged have been twice too high. Family labor has been overvalued. Besides, the value of the living obtained from the farm has not usually been added to income. If all of these were correctly calculated a result might be obtained that approximated total wages of management. But how separate the shares of landlord and tenant in this wage? In some cases, something like a market value for the tenant's share can be obtained by combining his labor and management and finding what the two together could be hired out for; but as for the value of the landlord's management, the case is hopeless. Therefore the plan of adjusting the shares in expenses according to particular situations is exceedingly difficult to work out accurately.

The nearest approach to such a plan as the foregoing would be to

have the tenant and landlord agree in advance as to a value to be placed on each of the foregoing items—rent, wages of family labor, wages of labor and management of the tenant, wages of the landlord's management, and value of living obtained from the farm. Interest on working capital and depreciation would also have to be agreed upon. In settling up the year's business, the cash expenses could be added to the foregoing, and either the farm income divided according to expenses, or expenses divided according to an agreed division of income. Ordinarily an inventory would not need to be taken, because each would share proportionately in the increase.

Such a plan as the foregoing may seem too involved for most circumstances. Following are two plans which are compromises between the above:

1. Follow the custom so far as possible, and when not possible make allowances for it in some other part of the lease. For example, if free fire wood for the tenant is the custom, and the farm has no firewood, the tenant can be given all the poultry, or a larger share of the poultry receipts. If a farm is too poor to rent well, the tenant can be given other advantages. Differences of this sort can if necessary be settled in actual cash at the end of the lease.

2. Count the tenant's labor and management, family labor and hired labor, and interest, taxes, depreciation and upkeep on his equipment, as equal to the landlord's mangement, interest, taxes, upkeep and depreciation on real estate and equipment. Divide the other expenses half-and-half, by estimating their amounts in advance, or by settlement afterwards.

The great merit of any plan which would divide income on the basis of expenses, or expenses on the basis of income, would be that it would give the tenant the full benefit of all the extra labor he hired.

RELATIONS BETWEEN LANDLORD AND TENANT

If landlords and tenants could be kept on better terms with one another, leases would be made for longer periods, herds would be broken up less often, and buildings and fences would be better maintained. The first essential to right relations between landlord and tenant is the choice of a suitable farm, the second essential is right choice of partners, the third is a thorough understanding when the bargain is made, and the fourth is a proper attitude toward each other in handling the various situations constantly arising under the operation of the lease.

A suitable farm. The suitable farm is one which is large enough, productive enough, and well enough located so that it will yield the tenant a good living and a surplus after the landlord's rent is paid. This is more important under share leases than under cash leases, because a cash tenant is free to work out if his farm is not large enough to keep him busy at home. Share tenants on dairy farms must be especially particular about the quality of the landlord's share of the herd.

Choice of landlord. Most common of all is the retired farmer, a good sort on the whole, but likely to be over-cautious about new enterprises, over careful with expense money, and slow about making improvements. Some of them need all the rent to make both ends meet in town. Where they have the means and modern business ideas and love their farms, they make the best of landlords. Another sort of landlord is the city merchant, banker, doctor, or lawyer who is investing his surplus in a farm, perhaps as something of a plaything, perhaps in order to profit on the rise in land values. Most of these men are good landlords, even if they are ignorant about farming. The real estate speculator is less desirable as a landlord—he is not enough interested in the business of the farm to want to make the needed improvements. There are now appearing in some sections a few landlords who are making the renting of farms on shares a profession. They obtain control of several farms in the same district, select high-class tenants, furnish them with half of a good herd of cattle, including a sire, lay out a plan of crop rotation, do the buying and selling, and give the tenant half the receipts. Most of the landlords now in this business are upright men and good managers and thus tenants prosper under their care. The plan, however, offers chances for abuse of the tenant.

The type of landlord chosen, however, is not half so important as his personal characteristics. Is he nagging, fault-finding, over-particular about small details? Is he firmly convinced that his notions as to farming are the best in the world? Or is he a reasonable, open-minded, sort of person interested in a tenant's welfare about as much as his own?

Choice of a tenant. Tenants in Wisconsin today are of two sorts, those who are getting ready to buy a farm as fast as they can, and those who are content not to make progress in that direction. In a few instances, the latter sort are properly ambitious, being convinced that renting pays better than owning. All the rest are thriftless hand-to-mouth fellows whom no landlord wants if he can help it. The first thing for a landlord to consider in a tenant, therefore, is his purpose in farming. It will pay him oftentimes to select a young fellow with very little means and help him to get started. Once a landlord gets a tenant of this kind, he ought, if possible, to keep him as long as he is willing to remain a tenant.

Written leases best. Written leases should be drawn up, agreed to and signed by both parties before the tenant moves onto the farm. If made out carefully and by and between the two parties, or in their presence, so that each and every provision is clearly and correctly understood, the chances are that the lease will never again be referred to. The lease is not the important thing; it is the understanding. But the only way to get a complete understanding is to put all the terms of the lease down in writing. Then, too, both parties are liable to death or accident at any time and it is well to have some written record that can be used in making settlement. For this reason especially,

written leases are fully as necessary between members of the family and relatives as between strangers.

Avoiding trouble: Rules for the landlord. Most of the troubles that arise between landlords and tenants under the operation of the leases center about the following things,—deciding what crops to grow; selling livestock; sharing expenses; making repairs and improvements, damages to buildings, division of receipts, especially poultry receipts, and division at the end of the lease. Following are a number of suggestions which successful landlords make time and time again as to the handling of tenants:

1. Keep your eyes on the big things about the farm enterprise, the things that are earning most of the money. Don't quarrel with a tenant over a basket of eggs or a broken window-light.

2. Help your tenant to make a good income. You may have to help him buy some good cows or horses or a corn binder, or hire him some extra help. But you can't afford to have either a cash or a share tenant on your farm who doesn't make money. The success of the tenant is what determines the rent.

3. Be not too free with advice, especially with a new tenant. Begin with a new tenant by doing him some real service, and soon he will be coming to you asking for advice. Indirect suggestions, when they are not insinuations, are much better received than advice.

4. Live up to the last letter of the agreement in what you are to furnish the tenant, especially in the matter of improvements. Repairs to the house and the cistern are most important of all. The housewife is probably overworking herself at the best.

5. In those things which are left to mutual agreement, avoid dictating to the tenant. Let his judgment rule if you cannot convince him that he is wrong, unless the matter is of great consequence. If you are convinced the tenant usually has poor judgment, and consequences of it are serious, wait till the end of the year and get a new one.

6. It is important to keep relations cordial. If they cannot be so maintained it may be best to find a new tenant.

7. If you have trouble with a tenant, first let things cool down. Then if need be, change tenants when the year is up.

8. Be absolutely regular about business dealings, settling all accounts strictly on time and in a business-like way. Let a bank keep your accounts if possible.

9. Do not figure so closely on small items as to give the impression of being mean and small.

10. Don't be guilty of counting the eggs in the nest-boxes, or the corn-cobs in the horses' feed boxes.

Avoiding trouble: Rules for the tenant—

1. Make the landlord trust you. You cannot afford to be guilty of the slightest irregularity or in taking the least advantage of the landlord. Uneasy is the lot of a suspicious landlord, and he will make the tenant's lot no less uncomfortable.

2. Keep your landlord feeling kindly toward you as long as you stay with him. It will cost you only a little forbearance and bring you many things you want.

3. Keep up the appearance of the premises. The farm is your home. It will pay in both money and satisfaction to give it a homelike aspect.

4. Take fully as good care of jointly owned property as you do of your own.

IS TENANCY DESIRABLE?

It is not the purpose of this bulletin to discuss in full the advantages and disadvantages of tenancy, but merely to point out a few of the important facts bearing on the question. Whether tenancy is desirable or not can be decided only by comparing it with its substitutes. These substitutes are as follows: (1) more farm laborers, (2) more and heavier mortgages, (3) smaller farms. The proportion of laborers

TABLE XI. COMPARING THE FARM BUSINESS OF OWNED AND RENTED FARMS IN 8 COUNTIES IN WISCONSIN, 1913–15.

	Farms Operated by			
	265 owners	148 share tenants	45 cash tenants	42 part owners
Number of acres	140	191	152	150
Value per acre	$86	$112	$97	$94
Value real estate	$12,814	$21,400	$14,800	$8,590[1]
Value equipment	2,614	4,150	2,790	2,290
Gross receipts[2]	2,071	2,815	1,893	1,904
Additional man labor[4]	339	323	318	308
Other currant expenses	526	607	505	548[3]
Depreciation	102	161	812	98
Net income	1,104	1,724	958	950
Interest on real estate[5]	314	525	363	211
Interest on equipment[6]	146	266	156	128
Farmer's wages	475	475	475	475
Profits	169	458	36	136
Profits plus living from farm[7]	564	858	364	536
Additional labor an acre	2.42	1.69	2.08	2.05
Equipment an acre	18.70	24.90	18.40	15.30

[1] Rented land (58 acres) not included.
[2] Includes increase in inventory.
[3] Includes cash rent on 27 cash rented acres.
[4] Includes family labor and hired labor.
[5] At 2.45 per cent. See Table II.
[6] At 5.6 per cent. See Table II.
[7] Living from farm reckoned at $400.

is constantly increasing as it is. In every 1000 agricultural workers in Wisconsin, 386 were laborers in 1910 as compared with 292 in 1880. There were only 25 more tenants in every 1,000 in 1910 than in 1880. In every 1000 owned farms in Wisconsin, 85 more were mortgaged in 1910 than in 1890. Wisconsin was the only state west of the Alleghanies in which the ratio of mortgage debt to value of farms increased between 1890 and 1910. The mortgaged farms in Wisconsin in 1910 were very much smaller and cheaper than rented farms, and noticeably smaller than the mortgage-free farms. Apparently Wisconsin farmers have freely chosen the substitutes for tenancy.

Table XI. compares the records of the rented and owned farms studied in eight counties of Wisconsin. The tenants are on the larger and more valuable farms and are making the largest incomes. The principal reason for this is, of course, that most of the tenants are found in southern Wisconsin where land values are higher. Share tenants are making larger incomes than cash tenants largely because they are most abundant in sections where land is valuable and farms quite large. The principal reason that owners are making less profits than share tenants is that many of the owners are older men who make a fair living farming in a leisurely manner with obsolete methods, whereas the tenants are wide-awake young men who are hustling to get a foothold on the agricultural ladder. In many neighborhoods, a larger proportion of owners than of tenants are poor, slack farmers. Mortgaged owners are no doubt as industrious as tenants, but they are handicapped because they are farming on smaller and poorer farms.

The significance of these figures is that they point out very clearly to all concerned what the usual choices are for a young man in Wisconsin with limited capital. He can migrate to a section of the state where land is cheap, or perhaps hunt out a small or a cheap farm in his own neighborhood. If he makes this choice, his income will ordinarily be small. Or he can rent a somewhat larger and better farm in some cash-renting neighborhood. His net income will probably be somewhat larger.* Or he can work some large and valuable farm in a share-renting neighborhood and make the largest income of all.

This comparison does not tell quite all the story. The age and experience of the young man needs to be considered. Tenancy, especially share tenancy, is an excellent apprenticeship in management. On the other hand, some young men work better and save better on their own farms than on rented farms.

Few thoughtful people desire a complete tenant system of farming in this country. On the other hand, many look with approval upon a moderate amount of tenancy. The facts seem to indicate that the young man on the Wisconsin farm will ordinarly fare better in his life's journey, if he considers the end as well as the beginning, and includes tenancy as one of the stages in his pilgrimage.

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* Attention should here be called to the fact that the cash-rent data presented do not include instances in southwestern Wisconsin and some other sections of the state where cash rent is most common.

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Fusarium Resistant Cabbage

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AGRICULTURAL EXPERIMENT STATION
OF THE UNIVERSITY OF WISCONSIN

MADISON

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Fusarium Resistant Cabbage[1]

The disease known as cabbage yellows is making impossible the successful culture of the cabbage in large and apparently increasing areas in the United States. Nearly ten years ago the senior author began a study of the disease in the Racine district of southeastern Wisconsin. This soon led to the development of a disease-resistant strain of the Hollander or Ball Head variety which has since been distributed and successfully grown commercially under the name Wisconsin Hollander. The general facts regarding the nature of the disease and the results with control measures, especially through disease resistance, were presented in an earlier bulletin.[2] Since that date the work has been continued with some advances both in regard to the study of the disease and the control measures.

Cause and development of the disease. Cabbage yellows is caused by the soil fungus *Fusarium conglutinans* Wollenw. This has been found by Tisdale[3] to penetrate the root hairs of the cabbage plants as does the similar flax wilt Fusarium, pushing thence back through the cortical tissues until it reaches the vascular system. The invasion of the vessels proceeds rapidly from the fibrous roots through the stem into the leaves. This leads to the progressive browning and death of the vascular elements followed by a slow yellowing of the aerial parts. The invaded plants soon begin to shed their lower leaves while making a weak effort at continued growth above. The disease may appear in the seed bed but is chiefly in evidence in the field after transplanting. In the worst cases in such field attacks, death may result in a week or two after the plants are set out. The

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[1] This work has been much strengthened because of the hearty support of Dr. W. A. Orton, head of the Office of Cotton, Truck, and Forage Crop Disease Investigations, U. S. Department of Agriculture. This office has contributed most of the services of Dr. J. C. Walker and has also met other expenses. It has further cooperated through Dr. J. B. S. Norton, who has successfully grown seed from selected heads in the Washington greenhouses during two winters. Both Dr. Norton and Professor L. L. Harter, also of this office, have offered valuable suggestions.

[2] Jones, L. R., and Gilman, J. C. The control of cabbage yellows through disease resistance. Wis. Agr. Exp. Sta. Res. Bul. 38. 1915.

[3] Tisdale, W. H. Flax wilt: a study of the nature and inheritance of wilt resistance. Jour. Agr. Res. XI: 573. 1917.

majority of "yellows" diseased plants continue their sickly existence for a few weeks, gradually succumbing, while some of those slightly invaded may live through the summer and even form heads.

When the soil is once infested, the fungus seems capable of persisting almost indefinitely, such soils being thereby rendered "cabbage sick." Even in the worst "cabbage sick" soils, however, there is a marked variation in severity of attack from year to year. This results from the fact first demonstrated by Gilman[4] that aggressive host invasion occurs only at relatively high soil temperatures, 17°C. (62°F.) and above. This means that the most serious development of yellows is limited to those seasons having relatively hot weather during the early part of the growing season and especially during the first month following transplanting, which is late June and early July in Wisconsin.

Distribution of the disease. In geographical distribution the disease seems to be rather widespread in its occurrence in the eastern United States[5] but it is not by any means universal in its ravages. It seems to be most serious commercially in the older and more intensive cabbage-growing sections from Iowa and southern Wisconsin across Illinois, Indiana, Ohio, Pennsylvania, Maryland, Delaware, and New Jersey. Northward the disease is certainly less prevalent in central Wisconsin, even in old cabbage growing areas, than it is in the southern part. Such data as are available from Michigan, New York, and lower Canada indicate that in these sections also, although present in the southern areas, it lessens as one goes northward. Farther southward its occurrence has been reported to us, but as soon as one passes to the regions where cabbage is grown as a winter or early spring crop the seriousness of the disease wanes. This is probably explained by the low soil temperature prevailing during the early growth of the crop under these conditions. The facts as to the distribution or minor occurrence of this parasite are especially hard to determine since the only evidence of its presence is the development of the disease in cabbage, and even

[4] Gilman, J. C. Cabbage yellows and the relation of soil temperature to its occurrence. Ann. Mo. Bot. Gard. 2: 25. 1916.

[5] Harter, L. L., and Jones, L. R. Cabbage diseases. U. S. Dept. Agr. Farmers' Bul. 925. 1918.

where this occurs it is often difficult for one not quite familiar with both diseases to distinguish it with certainty from the bacterial black rot.[6] The reported distribution seems to accord with the conception that the cabbage Fusarium is widely distributed in the United States, at least from the Mississippi Valley eastward, and that the serious development of the disease where intensive prolonged cabbage culture occurs is conditioned upon favorably high soil temperatures during the early stages of development of the plant. It is noteworthy in this connection that the disease has not been found[7] in the cabbage fields of Holland and Denmark although these include the oldest and most intensive cabbage districts of the world. It has not developed in the cool soil of the Puget Sound coast. Whatever its present distributional limits, there seems to be good ground for believing that in the United States it is certain to be introduced sooner or later into all parts of the country where cabbage culture is long practiced and that once introduced it will persist and spread wherever soil temperature conditions permit. In the earlier bulletin[8] trials were recorded with various measures aiming at the control of the parasite after once introduced. All of these, save selection for disease resistance, gave negative results. The conclusion was reached, therefore, that it is only through securing Fusarium-resistant strains, suited to local market and climatic conditions, that the cabbage industry can be developed on a sound, permanent basis in most parts of the United States. Work to this end has, therefore, been continued with the cooperation of the United States Department of Agriculture. This has included, (1) further work with the Wisconsin Hollander; (2) the development of resistant strains of other varieties, especially of late summer types used largely for the manufacture of sauerkraut; (3) cooperation with growers and commercial

[6] Jones and Gilman, Wis. Agr. Exp. Sta. Res. Bul. 38, p. 9.

[7] This statement is based upon the judgments of Dr. F. Kölpin Ravn, of Denmark, Dr. Johanna Westerdijk, of Holland and Dr. Otto Appel of Germany, each of whom some years ago saw the disease as it occurs in Wisconsin. Further evidence of the non-occurrence of the disease in the cooler climates of Europe and Asia has been secured in 1919 during visits to our trial grounds of the following foreign pathologists, none of whom had previously met with it, Messrs. G. H. Pethybridge, Ireland, A. D. Cotton, England, Ivar Jorstad, Norway, and K. Nakata, Japan.

[8] Jones and Gilman, loc. cit.

organizations in the production and distribution of seed of the resistant strains; (4) further studies on the relation of environment to the development of the disease.

RECENT WORK WITH WISCONSIN HOLLANDER

The name Wisconsin Hollander was given in the earlier bulletin to the Fusarium-resistant strain selected from the commercial Hollander or Danish Ball Head. For the details concerning this, reference may be made to the former publication.[9] The large commercial cabbage growers of Wisconsin are interested only in one or the other of two types of cabbage: (1) the late variety, Hollander or Danish Ball Head, used for winter storage purposes, (2) the earlier varieties for immediate use chiefly in the local kraut factories. The first of these takes the lead in most parts of Wisconsin and has therefore merited such further attention as was necessary to its commercial distribution and use. This has involved during the last five years the critical watching of its growth in commercial fields under different environmental conditions, attempts at possible further improvement, and attention to the growing and distribution of adequate supplies of seed.

WISCONSIN HOLLANDER IN COMMERCIAL FIELDS

During the last five seasons, 1916–1920, the Wisconsin Hollander has been grown commercially on a constantly increasing acreage in the older Racine-Kenosha cabbage soils. The seed has been grown locally either by individual farmers or under the supervision of a growers' committee organized for this purpose. In 1916 there was sufficient seed distributed for widespread planting, though on a limited scale. Since 1917 the supply has been reasonably adequate for local needs. To determine for themselves the relative merits of the yellows-resistant Wisconsin Hollander as compared with the non-resistant commercial strains, cabbage growers were urged during the first two seasons, 1916 and 1917, to plant at least one or more rows of some commercial type in the same field with the Wisconsin Hol-

[9] Jones and Gilman, loc. cit.

lander and observe the results. They were very striking. In 1916 during the hot weather of July, the disease was unusually destructive. Figure 1 shows some of the evidences which convinced the cabbage growers that even under these most trying conditions of 1916 they could succeed with the home-grown

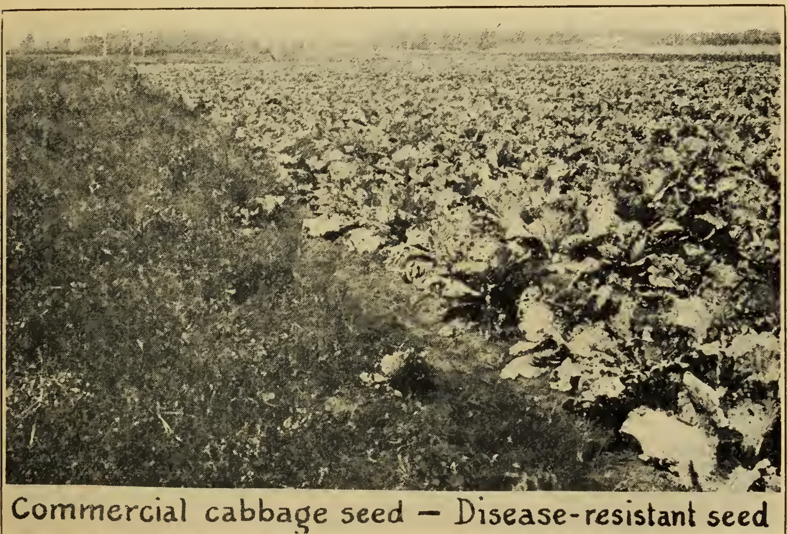

FIG. 1.—WISCONSIN HOLLANDER VS. COMMERCIAL HOLLANDER ON SICK SOIL

A farmer's trial of Wisconsin Hollander in 1916 (Scheckler's third field, Table I). The Commercial Hollander cabbage which was planted on the left was practically destroyed by yellows and the ground was occupied by weeds. The Wisconsin Hollander in balance of field, at the right, gave a highly profitable crop.

seed of Wisconsin Hollander when the non-resistant strains of Hollander were a commercial failure. Counts were made in late August of the percentage of plants showing signs of yellows in each of these fields where the Wisconsin Hollander was planted beside a comparable commercial variety. The results were as follows from the twenty fields.

TABLE I.—RESULTS OF COMMERCIAL TRIALS OF WISCONSIN HOLLANDER RESISTANT COMPARED WITH A SUSCEPTIBLE COMMERCIAL STRAIN. RACINE DISTRICT. 1916. (SEE FIGURE 1 FOR APPEARANCE OF ONE OF THESE FIELDS.)

Name of Grower	Percentage of yellows	
	In Wisconsin Hollander	In commercial Hollander
Bartholomew	22.5	92.0
Hansche, A. & S.	14.3	91.0
Hansche, A & S. (second field)	11.0	86.0
Hansche, Fred	17.0	86.5
Hansche. L. E.	12.8	50.0
Klapproth	43.7	94.7
Piper	22.7	90.3
Drummond	33.7	93.7
Horner	23.9	85.8
Braid	54.6	100.0
Kraus	25.3	73.0
Scheckler	21.7	98.0
Scheckler (second field)	30.0	98.8
Scheckler (third field)	17.8	94.5
Jacobson	15.6	91.2
Broesch, M	30.2	98.3
Broesch H.	27.2	93.2
Thompson Bros	33.6	85.2
Lichter	11.7	89.6
Abresch	17.5	88.4
Average of twenty fields	**24.3**	**89.0**

As shown by the foregoing averages, less than one-fourth of the Wisconsin Hollander plants showed Fusarium infection, whereas the commercial strains averaged nearly 90 per cent. These figures are not nearly so striking as was the actual appearance of the fields. This is due to the fact that in most cases where the disease did occur in the resistant strain it was so slight that the plants listed as having yellows usually formed good-sized heads, whereas most of those attacked in the commercial strains either died early in the season or formed no heads if they lived.

Results in 1917. In 1917 several growers continued to plant one or two control rows of commercial cabbage in the field with the Wisconsin Hollander for purposes of comparison. The disease was less severe than in 1916, but prevalent enough to show a large gain where the resistant strain was used. Table II gives the results from four of the "sick" fields where such control rows were included in the planting.

TABLE II.—A COMPARISON OF WISCONSIN HOLLANDER AND COMMERCIAL HOLLANDER IN FARMERS' FIELDS, 1917.

Name of grower	Strain of seed	Per cent of yellows
Thomas	Wisconsin Hollander	2
	Commercial Hollander	50
Lichter	Wisconsin Hollander	5
	Commercial Hollander	88
Horner	Wisconsin Hollander	10
	Commercial Hollander	75
Johnson	Wisconsin Hollander	7
	Commercial Hollander	97

This shows an average of only 6 per cent of yellows in the Wisconsin Hollander as compared with nearly 80 per cent in the commercial strains.

Results in 1918–19. During the two seasons 1918 and 1919 the cabbage growers having "sick" soil accepted the evidence of the superiority of the Wisconsin Hollander and ceased to plant non-resistant controls in their fields. Comparisons that could be made were those in our trial grounds where, under the conditions of 1918, no yellows whatever was evident in the best resistant selections and the average of all Wisconsin Hollander selections under trial showed less than 1 per cent of diseased plants whereas the commercial control showed about 85 per cent.

In 1919, owing to the hot dry weather in July, the disease was much worse than in 1918. The result was that a large percentage of the plants of even the most resistant strains of Wisconsin Hollander showed some indications of infection, the average of all strains being about 70 per cent. Most of these were slightly diseased, however, and 80 per cent lived through the season, whereas of the non-resistant controls every plant showed yellows and only 1 per cent lived through the season.

The results under the most extreme climatic conditions and in the various types of soil have, therefore, continued fully to justify confidence in the practical merits of the Wisconsin Hollander as originally distributed. Efforts have been kept up, however, during this time to improve upon it in any way practicable.

EARLY WISCONSIN HOLLANDER, A NEW STRAIN

The Wisconsin Hollander was selected from the strain of the Hollander or Danish Ball Head. In the subsequent trials of this selection beside the original Ferry[10] Hollander the former has proved to be more vigorous, to have a little longer stem, a more flattened head, and to require a longer season for maturing. (See Fig. 2.) While this makes it a somewhat heavier

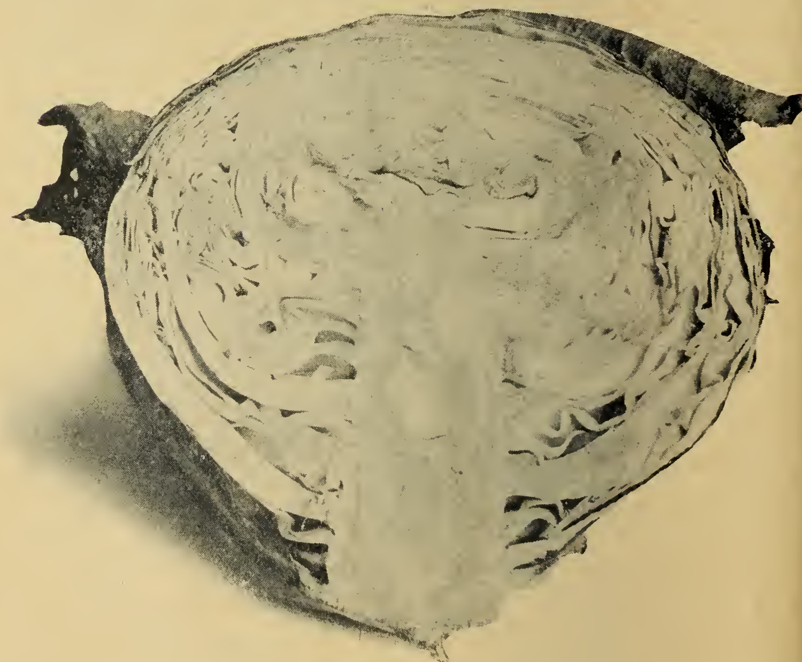

FIG. 2.—LATE WISCONSIN HOLLANDER

Section of a typical head of Late Wisconsin Hollander cabbage. In comparison with the Early Wisconsin Hollander, (Fig. 3), note the coarseness in texture, and tendency toward "flattening."

yielder in seasons having a favorably long autumn, under less favorable conditions, it may fail to mature as large a percentage of heads. In any case the date of harvest and marketing is delayed somewhat. In the judgment of representatives of the seed company and of W. J. Hansche, secretary of the local cabbage growers' committee, it has seemed commercially desirable

[10] In making our recent comparisons with the original Ferry type we have had the helpful cooperation of Mr. Coulter and Mr. MacKinnon.

to try to secure a strain through further selection from the Wisconsin Hollander which would more fully combine with disease resistance the original Hollander characters of earliness, round head, and short stem. Owing to Mr. Hansche's skill, gained through long experience in handling and judging Hollander cabbage, we have in recent years left with him the immediate responsibility for the head selections with this in view. Each season we have included in our trial grounds such head strains as

FIG. 3.—EARLY WISCONSIN HOLLANDER

Section of a typical head of Early Wisconsin Hollander cabbage. In comparison with Late Wisconsin Hollander (Fig. 2), note the compactness, close grain and shape approaching the spherical. This is accepted by expert practical growers and representatives of commercial seed houses who have inspected the trial fields as meeting the highest standards as a winter or storage cabbage type. The desired type is combined with a high degree of resistance to yellows.

he has selected in order to determine their relative disease resistance. A strain has thus been secured which combines well the desired characters. This has descended from a single head which Mr. Hansche selected in a field of Wisconsin Hollander in 1916. The seed plant from this head was forced in the greenhouse during the winter of 1916–17 and from a few seeds thus secured by self pollination plants were grown for trial in 1917. Owing to the late maturity of the seed these plants were forced

in a cold frame apart from the other strain, hence they could not be closely compared with the latter as to disease-resistant quality. They made an excellent showing in this respect, however, and also maintained well the round head and short stem of the parent plant, while, considering their late start, they matured somewhat earlier than the other Wisconsin Hollander strains. All of the sound heads of this strain were saved and set out for seed growing in an isolated plantation in 1918. Seed from one of the best of these plants was saved as a separate head strain for the 1919 trial grounds, the balance mixed for field use. The results in all cases were highly satisfactory in that along with a degree of disease resistance fully equal to that of the older strains of Wisconsin Hollander, these plants showed with much uniformity the desired characters for which the parent head was selected—shorter stem, rounder head, and earlier maturity. (See Fig. 3.) In these respects the new type is closely similar to the original Ferry Hollander. Under the conditions of 1919 the field crop of the recent selection matured nearly two weeks earlier than the older type of Wisconsin Hollander. To distinguish the two types, the new one will hereafter be designated as the Early Wisconsin Hollander and the older strain, now in general use, as the Late Wisconsin Hollander. It is hoped that commercial growers and seed dealers who may use these strains will cooperate with us in maintaining them independently since they represent types worthy of such segregation. Apparently one or the other of these types will meet adequately the needs in the various sections where the Hollander cabbage is now grown in a large commercial way. In order to provide for this, the available seed of the Early Wisconsin Hollander has been sent to the Puget Sound region for the production of a seed crop which should be available for commercial distribution in 1921.

RESISTANT SELECTIONS OF OTHER VARIETIES

The Hollander, which is a winter storage or shipping cabbage, is the variety of chief commercial interest in Wisconsin. With the development of this winter cabbage industry, however, has come an increasing number of kraut factories. These use little or no Hollander cabbage as a rule, the needs of this industry being best met by special types of the late summer or "domestic" cabbages of the Flat Dutch group. Of these kraut varieties the

one in most favor in the Racine district—when the present problems were outlined—was the Brunswick. In other kraut-growing sections the All Seasons is generally preferred. Since both of these are rather late fall varieties the All Head is generally grown in addition for early kraut use because it has a reputation for sure heading, desired kraut quality, and matures a week or more in advance of either All Seasons or Brunswick. Accordingly, efforts have been made to secure resistant strains of each of these three kraut types beginning with the Brunswick.

WISCONSIN BRUNSWICK

The first selections were made in a badly diseased field in 1913. The seed from which this field was grown was supplied by Mr. F. W. Gunther, kraut manufacturer of Racine, and was imported from Germany by him. Trials of the original or commercial strain of this seed made in 1912 and 1913 as reported in our earlier publication[11] (pp. 34, 35) showed it to be about as susceptible to yellows as the average commercial Hollander varieties and this accords with the general experience of Racine cabbage growers. Seed was grown from two of these selected heads in 1914 and tested in our 1915 plots. The results showed these selections to be distinctly superior in Fusarium resistance to the parent commercial strains. Fortunately the progeny of one head proved distinctly better than the other and to be of good Brunswick type. Its behavior as compared with the non-resistant control is shown in Table III. Selections of heads for further seed growing were made from this one head strain. It should be noted that 1915 was an unusually cool summer and that consequently the yellows disease was not very bad even in the control plants.

TABLE III.—RESULTS IN 1915 WITH THE BEST FIRST GENERATION SELECTION OF BRUNSWICK CABBAGE.

Strain	Yellows	Living	Headed
	Per cent	Per cent	Per cent
Selected Brunswick (XI-4-2)	18	100	95.0
Control (Commercial Hollander)	84	85	76.1

[11] Jones and Gilman, loc. cit.

Further trial was therefore made of this head strain (XI–4–2) in 1916 on thoroughly sick soil. Owing to the warm weather favorable to the disease this season they underwent an especially severe test. Only one plant out of 45 of these Brunswick heads was seriously infected with yellows while the commercial variety planted alongside was practically destroyed by the disease. The evidence from the trials of the two seasons taken in combination justified the conclusion that this selection represented a sufficiently resistant type of Brunswick to warrant its perpetuation for distribution to the growers. Several of the most desirable heads were therefore selected for further seed growing in 1917.

TRIALS OF SECOND GENERATION BRUNSWICK SELECTIONS IN 1917

In 1916 seed representing the second generation was secured from a number of the heads selected in 1915 and these were tested in 1917 under their respective serial numbers with the following results. This 1917 trial was on the same soil which had been proved so sick in 1916 and the season was sufficiently favorable again for the Fusarium to give a good trial.

TABLE IV.—RESULTS WITH SECOND GENERATIONS OF BRUNSWICK SELECTED IN 1915 AND TESTED IN 1917.

Head Strain	Plants infected	Plants killed by yellows
	Per cent	*Per cent*
No. XI—6—12	17	4.2
No. XI—6—15	22	2.0
No. XI—6—13	25	5.8
No. XI—6—11	25	7.7
No. XI—6—10	35	7.5
Commercial Brunswick, control	80	54.0

A small quantity of the resistant Brunswick seed was also given out for trial by growers in 1917 and fortunately some of these plants were placed in a field at Union Grove, Wisconsin, where the soil was quite "sick." A visit to this field in September showed the selected strain to be standing up almost perfectly while commercial strains alongside it were badly affected by yellows. (See Fig. 4). In 1917 a small amount of this seed was placed with other state experiment stations for trial. Sc

far as we know only one sample was planted on Fusarium sick soil. This was placed through the cooperation of Prof. H. S. Jackson of the Indiana Experiment Station with M. Humpfer at Hammond, Indiana. In October, Mr. Humpfer reported that with this he planted 10,800 square feet, or about one-quarter acre of badly diseased land. It gave him about 98 per cent stand, yielding 5 tons of cabbage. On one side of this he had commercial Copenhagen Market which gave only 25 per cent of

FIG. 4.—RESISTANT WISCONSIN BRUNSWICK

Cabbage trials on Fusarium sick land made by a farmer in 1917. One row of Wisconsin Brunswick (resistant) at right of center showing complete stand; balance of field on the right was Wisconsin Hollander, also resistant; remainder of field at left commercial Hollander (non-resistant) where the loss was due partly to yellows and partly to black leg.

a stand and on the other, commercial Glory of Enkhuizen which gave 50 per cent of a stand. He tried Wisconsin Hollander on the same field and found that this and the Brunswick showed about equally high resistance, the Hollander giving a 95 per cent stand whereas commercial Hollander alongside gave about a 33 per cent stand.

While the results to date have not in general shown the Brunswick strains quite equal in resistance to the best Wisconsin Hollander strains, the trials have justified the conclusion that the best selected strain deserves commercial distribution and the

seed has therefore been put out under the name Wisconsin Brunswick.

TRIALS OF WISCONSIN BRUNSWICK IN 1918 AND 1919

Trials of 1918. The trials of Wisconsin Brunswick were repeated on "sick" soil at Racine in 1918 using four of the head strains of seed grown in 1917 with the encouraging results shown in Table V.

TABLE V.—RESULTS WITH THIRD GENERATION OF BRUNSWICK SELECTED IN 1916 AND TESTED IN 1918.

Strain	Plants showing yellows
	Per cent
Wisconsin Brunswick head strain No. XI—7—1	0.0
Wisconsin Brunswick head strain No. XI—7—3	0.7
Wisconsin Brunswick head strain No. XI—7—4	0.7
Wisconsin Brunswick head strain No. XI—7—8	8.3
Commercial Brunswick, control	69.9

Trials of 1919. Owing to the severe midsummer heat the trials of 1919 were unusually severe. In 1918 seed had been secured from only one new head strain of Brunswick, XI–8–1. Therefore, two of the head strains from which seed was grown in 1917 were included, X1–7–1, which had proved the best of those tested in 1918, and XI–7–10, a strain which had been omitted through lack of room from the trials of 1918. Since no commercial Brunswick of reliable character was available for control purposes, comparison is made with the commercial Hollander planted in the trial grounds.

TABLE VI.—WISCONSIN BRUNSWICK TRIALS, 1919.

Head strain	Yellows	Lived	Headed
	Per cent	*Per cent*	*Per cent*
Wisconsin Brunswick XI—8—1	54.8	96.7	23.9
Wisconsin Brunswick XI—7—1	16.2	97.6	67.5
Wisconsin Brunswick XI—7—10	55.2	86.5	64.2
Control, commercial Hollander	98.9	9.3	7.6

Since the evidence is clear that the 1918 strain, XI–8–1, was inferior in disease resistance to both of the 1917 strains, XI–7–1

and XI–7–10, heads for further seed growing were saved only from the latter.

These trials have shown that the Wisconsin Brunswick which is now available in limited quantities for commercial use combines very well the type of the commercial Brunswick with a sufficiently high degree of disease resistance to meet practical needs. Conferences with various growers have shown, however, that while the Wisconsin Brunswick possesses many good qualities both the commercial and the selected type have certain char-

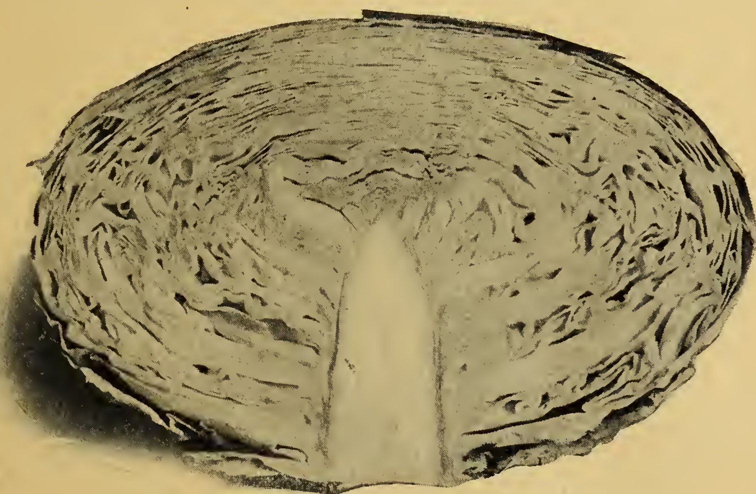

FIG. 5.—TYPICAL BRUNSWICK HEAD

Section of Wisconsin Brunswick cabbage. Note the relatively flat head and openness of spaces between the leaves of this and the other kraut type (See Fig. 6) as compared with the round, dense, hard heads of the Hollander or storage cabbage type (See Figs. 2 and 3). The characteristically very short stem or "core" of the Brunswick is also illustrated here. This commends it to the kraut manufacturers, but is not so satisfactory to the grower inasmuch as it is associated with the tendency to form a reëntrant angle at the base as explained in the text.

acteristics which stand in the way of their general acceptance for commercial kraut growing. Because of the very short stem and relatively thin flat head when they grow very large, the head tends so to thicken at the sides as to form a reëntrant angle with the stem. The result is that the heads cannot be cut from the stem at harvest so easily and quickly as the All Seasons and other standard kraut types. Since it was considered possible to overcome this trouble in some degree at least, a number of heads which possessed this reëntrant stem in the minimum degree were selected from the resistant plants in the 1919 trial field. (See Fig. 5.) These have been stored for seed growing and further

trial. Since this will be a work of several years at best the resistant Wisconsin Brunswick corresponding to the commercial type will be placed in commercial distribution.

WISCONSIN ALL SEASONS

The All Seasons belongs to the same group of mid-season Flat Dutch cabbage as the Brunswick but it has a somewhat longer stem and rounder head. Because of type, quality and season

FIG. 6.—WISCONSIN ALL SEASONS

Section of typical head of Wisconsin All Seasons cabbage. This selection conforms closely in type to the standard All Seasons of the American seed trade which is a favorite variety with the majority of kraut growers. A comparison with figures 2 and 3 shows the differences between the kraut and the storage types as explained under figure 5. As compared with the Brunswick (Fig. 5) the All Seasons head is deeper with longer stem or "core," and is more rounded at the base.

it has become the standard kraut cabbage and is more widely used than any other single variety in the United States. (See Fig. 6.) Although the needs of the Wisconsin growers of the Racine district seemed fairly well met by the Wisconsin Hollander and Wisconsin Brunswick, these two varieties did not adequately meet the national situation. This fact was brought out by a survey of the kraut interests of the United States generally, undertaken jointly a few years ago by L. L. Harter and

the senior author on behalf of the Federal Bureau of Plant Industry, which showed that the second tier of states, extending from Iowa to the Atlantic seaboard, is suffering serious loss from the Fusarium disease and prefers in general the All Seasons for kraut purposes. This is preëminently the case in the Illinois, Indiana, and Ohio districts.

Since our experience has led us to believe that it is possible through selection to secure a Fusarium-resistant strain from any of the standard cabbage varieties without breaking up the horticultural type with which one is dealing, it was early decided that the next effort should be directed to securing a disease-resistant strain of All Seasons. Reference was made in our earlier bulletin[12] to the fact that Manns of the Ohio Experiment Station suggested the possibility of overcoming cabbage yellows through disease resistance. Through correspondence with Professor Selby of the Ohio Station we learned in 1914 that S. N. Green of the horticultural department of that station had already undertaken selections for this purpose. Upon request of Professor Selby, Mr. Green kindly sent us some of the seed of the most promising strain which he had selected from heads of All Seasons variety as grown in the Clyde, Ohio, district, and we sent some Wisconsin Hollander seed in return. This was tested in our 1915 series, alongside the Wisconsin Hollander and commercial varieties, and corresponding tests were made the same year near Clyde, Ohio, by J. G. Humbert of the Ohio Experiment Station, department of botany. The outcome showed that this selection of All Seasons had little if any greater disease resistance than the commercial varieties. Prof. W. J. Green of the Ohio Station recently advised the senior author that S. N. Green was no longer connected with their station and that the selections had not been continued. Although most of the plants in this strain of All Seasons in 1915 were diseased, a few appeared free from Fusarium and with the assistance of certain experienced kraut growers who inspected the field, several of the most promising of these heads were selected for seed growing. In order to save time some of these were sent to C. W. Edgerton of the Louisiana Experiment Station for winter seed growing. Seed from one of these (XXV–6–3) was returned in the spring of 1916 in time to be included in the trial grounds that year.

[12] Jones and Gilman, loc. cit.

TRIALS OF 1916 AND 1917

The disease was very severe on the trial ground in 1916 so that of the 55 selected All Seasons plants set out only six escaped infection, whereas of the selected Brunswick alongside only one plant of 45 was infected. The six heads which escaped infection were saved for seed growing and again, in order to save time, two of the most promising of these were selected for winter forcing. We were favored by the cooperation of Prof. J. B. Norton of the Bureau of Plant Industry and he secured seed from these in the greenhouse at Washington and returned to us in the spring of 1917 as follows: head strains XXV–7–2 and XXV–7–8, each grown from a single selfed plant, and strain XXV–7–2 x 8 which was the result of the crossing of these two. In addition, we had for inclusion in the 1917 trial grounds some 14 head strains of the first generation selections (XXV–6–3—XXV–6–23) grown at Madison in 1916 from heads saved in 1915. These, therefore, represented our first general selections, comparable to those tested in 1916. Furthermore, these had been grown in mixed plantation. The comparative results as shown in the following table are unusually interesting since they illustrate clearly the advantage at this stage in the work of selfing or close pollination as compared with growing in mixed plantation.

TABLE VII.—RESULTS FROM TRIALS OF SELECTED ALL SEASONS HEAD STRAINS IN 1917.*

Strain No.	Pollination	Yellows	Killed by yellows
		Per cent	*Per cent*
XXV—7—2	selfed	5	0
XXV—7—8	"	4	0
XXV—7—2x8	crossed	2	0
XXV—6—4	mixed	28	8
XXV—6—5	"	39	10
XXV—6—6	"	37	0
XXV—6—9	"	35	4
XXV—6—10	"	40	6.9
XXV—6—11	"	39	4
XXV—6—12	"	43	6.2
XXV—6—14	"	21	0
XXV—6—15	"	40	5
XXV—6—16	"	39	2
XXV—6—17	"	33	6.4
XXV—6—21	"	51.6	7.3
XXV—6—22	"	29	4
XXV—6—23	"	16	2.4
Commercial All Seasons Control		**80**	**46**

* Figure 7 shows the appearance of these plants in the field.

The showing made by all three strains of second generation seed which Professor Norton had secured was thus very encouraging indeed, both by contrast with the 1916-grown first generation strains and with the commercial. (See Fig. 7.) Thus where the commercial strain showed 80 per cent of Fusarium infection and one of the best first generation strains, XXV–6–23, showed 16 per cent, Norton's hybrid XXV–7–2 x 8 showed only 2 per cent, and the selfed strains scarcely more. This was a distinctly

FIG. 7.—ROW OF THE MOTHER HEADS OF WISCONSIN ALL SEASONS

Trial grounds of resistant All Seasons, 1917. Soil very sick, see Table VII. Commercial All Seasons in center practically destroyed by yellows. Second generation selections, XXV–7–2 and XXV–7–8, in the next two rows at the right. Of these XXV-7-2 was the best type and from it the finest heads were selected for propagation as Wisconsin All Seasons. The remaining rows at the right are the first generation selections of the same variety, which, proving less desirable, were discarded.

better showing than was made in the same parallel trials the same season with the resistant Brunswick selections and nearly as good as the best Wisconsin Hollander. It seemed clear, therefore, that we had at least three highly resistant strains of All Seasons from which to select for further increase. All were of good appearance but upon critical comparison, in which we had the advice of L. D. Coulter, cabbage expert of the D. M. Ferry Co., strain XXV–7–2 was considered to represent the best and most uniform type. Our own selections for further seed growing were restricted to this strain.

Further trials and selections have been continued with this strain of All Seasons during 1918 and 1919. The 1918 trials showed in this resistant strain (XXV–7–2) only slightly over 1 per cent of yellows and almost a full stand of heading plants (over 98 per cent) whereas the non-resistant control showed over 60 per cent of yellows and only about 15 per cent heading. In 1919, when the disease was severe owing to the high summer temperature, this strain made a very good showing, and in general proved more resistant than the best Wisconsin Hollander. Meanwhile, sufficient seed has been producd from the 1917 and 1918 selections to enable the Wisconsin cabbage growers' committee to inaugurate seed growing on a commercial scale. As will be explained later, arrangements have been made by which seed growing of the resistant All Seasons is also being carried on in a trial way under supervision in the Long Island and Puget Sound sections in addition to what is being grown in Wisconsin. The first of this seed will be ready for distribution in the autumn of 1920 under the name of Wisconsin All Seasons.

SELECTIONS OF OTHER VARIETIES

Maryland Flat Dutch. Early in our work upon the Wisconsin Hollander we learned that Close and White[13] of the Maryland Experiment Station had been noting a difference in the susceptibility of cabbage varieties to what they termed black rot; and upon our request in 1913 Professor White sent us a sample of a strain of Late Flat Dutch which they had selected and grown for such rot resistance. Owing to its origin we have termed this the Maryland Flat Dutch. This Maryland strain proved highly resistant to yellows in our 1914 trials. (See Fig. 8.) Several heads were saved from this 1914 trial and seed was grown from some of them in 1915.

Since the type did not interest the Wisconsin growers who inspected this field we did nothing more with the Maryland strain until 1919. Learning from recent conferences with kraut packers of other states that they and some other commercial cabbage interests have need for a domestic variety somwhat later in maturing than the All Seasons we decided to include some of these head strains (XXIV–5–1, XXIV–5–2, XXIV–5–3, XXIV–5–4)

[13] Close, C. P. and White, T. H. Cabbage experiments and culture. Md. Agr. Exp. Sta. Bul. 133. 1909.

in our trial plantings in 1919. They proved to be fairly resistant, being in this respect about in the class with the Wisconsin Brunswick but not equal to the better strains of Wisconsin All Seasons or Wisconsin Hollander. The type did not prove altogether satisfactory. Probably because not well suited to Wisconsin climatic conditions, especially under the high summer temperature of 1919, it did not form as large a percentage of firm heads as the other domestic varieties under trial. Further selections of the best head types were made from the more prom-

FIG. 8.—FUSARIUM-RESISTANT MARYLAND FLAT DUTCH

Trial of Maryland Flat Dutch, 1914. Three rows at right showing a practically full stand are of this variety; the next three rows at the left are commercial Houser, slightly resistant; the next three rows, with only one plant still alive, are commercial Hollander. Several of the best heads of this Flat Dutch were saved for seed growing in 1915 and gave us the head strains XXIV–5–3 and XXIV-5-4 referred to in the text.

ising strains, XXIV–5–3 and XXIV–5–4, and further selection will be made from these. Professor White advises us that he has continued to propagate this strain and that it is in successful use in Maryland.

All Head Early. The kraut packers with whom we have conferred pronounce this the favorite variety for early kraut purposes. It belongs to the early Flat Dutch group and is said to be the best cabbage of its type ever produced in Long Island where it was developed by a Mr. Strang a generation ago.[14] It

[14] Allen, C. L. Cabbage, cauliflower and allied vegetables. 1915.

has a reputation for uniformity, tenderness, and sureness of heading which make it the most promising variety of the early group from which to undertake selections for disease resistance. While for kraut purposes it is similar to the All Seasons, it is somewhat earlier in maturing, thus prolonging the packing season. A considerable acreage of this variety was grown in 1919 under contract with the John Meeter & Sons Kraut Co. in the western part of Racine and Kenosha Counties. Through the cooperation of Martin Meeter we located a field of All Head Early where the yellows was very bad (See Fig. 9) and selected for seed growing some twenty heads of good type, apparently disease-free. It is hoped that the seed secured from these may be used for further trial and selection.

FIG. 9.—ORIGINAL SELECTIONS OF ALL HEAD EARLY AND GLORY OF ENKHUIZEN

Field of commercial All Head Early and Glory of Enkhuizen cabbage practically destroyed by yellows, at Union Grove, Wis., in 1919. Typical seed heads were selected from the few remaining resistant plants for seed production in 1920.

Glory of Enkhuizen. This is grown especially in certain sections of the east as a standard mid-season kraut variety and its use is apparently increasing in the northern Mississippi Valley. Some of this had been planted in the same "sick" field with the All Head and at least 77 per cent of the plants were killed and many of the rest showed yellows (Fig. 9). Advantage was taken of the opportunity to select heads for seed growing in 1920. It is hoped that a disease-resistant strain of this, also, may ultimately be secured.

Copenhagen Market. This is an early cabbage of excellent quality which has recently come into much favor for market garden uses and in certain localities is grown for kraut. One of the important centers of its culture is Muscatine, Iowa.

Since the yellows is serious there Drs. I. E. Melhus and J. C. Gilman of the Iowa Experiment Station have been working some two years to secure a resistant strain of this variety, and trials made in our fields in 1919 with some of the seed which they sent for this purpose, showed distinct progress toward this end with at least two strains. Inasmuch as neither of these Iowa strains conformed exactly to the standard commercial type we made additional selections from a "sick" field of Copenhagen Market near Union Grove, Wisconsin, in the autumn of 1919. It may be expected that ultimately either the Iowa or Wisconsin selection or both may furnish the desired type combined with disease resistance.

PRESENT STATUS SUMMARIZED

It is evident that individual variation in degree of susceptibility or resistance to Fusarium has been found to occur with every variety of cabbage tested on "yellows sick" soil. Experience to date justifies our confidence that this resistance is due to heritable differences and that, therefore, through the selection of such resistant heads from "sick" soil, a Fusarium-resistant strain may be secured of any of the standard cabbage varieties Our experience indicates moreover, that through careful and repeated selection this resistance may be combined with any of the other desired qualities of the standard commercial varieties, such as season of maturity, length of stem, tenderness of leaf, shape and compactness of head. In other words, resistance does not seem to be incompatible with any other of the commonly recognized variables of the cabbage. All our experience indicates that Tisdale's conclusions relative to the flax wilt[15] hold true for the cabbage, that resistance is probably determined by multiple factors. The degree of resistance is, therefore, due to the combination of these and in all cases in our experience it is partial or relative, not absolute. Moreover, this explanation is consistent with our experience that after proceeding to a certain stage with our present methods of selection little or no further progress as to disease resistance is made. This is also consistent with our general experience that the best results have in each case been secured through growing a selected head in isolation

[15] Tisdale, W. H. loc. cit.

and thus securing seed through self-pollination, but that when the benefits were once secured in this way with our best selections mass culture has been followed to advantage.

Our plan of procedure, justified alike by theory and practice, is as follows. After securing a strain showing a satisfactory degree of resistance, combined with the other desired characteristics, we release it for commercial distribution. Thereafter, our interest is primarily confined to such cooperation as is required for the maintenance of these essential standards. To this end we continue to grow each year a few hundred plants of each of these types in trial rows on soil that is "sick," i. e. thoroughly infested with the cabbage Fusarium. From these plants further selections are made with the aim of maintaining the best standards both as to type and disease resistance. Of course, there is opportunity for minor gains in this way, but our experience has not indicated that much improvement is to be expected in this direction. The surplus seed thus obtained is placed in hands of the local cabbage growers' committee for commercial increase in such manner as will best maintain general standards of excellence.

All our experience has shown that in seasons when high soil temperatures—especially during July—favor the development of yellows there will be a considerable percentage of the plants even in the most resistant of these strains which shows evidence of incipient yellows. Most of these proceed with their development to full maturity and form good heads so that the commercial loss is rarely large even in the worst cases. While the amount of the disease varies considerably with other factors such as soil and drainage, there is no evidence that the resistant character of the selected strains breaks down under any of these conditions except in the young seedling stage. The studies of W. B. Tisdale[16] have shown that seedlings of the resistant strains grown in sick soil at a temperature favorable for the development of the disease succumb almost as readily as those of susceptible strains. The plants, however, acquire a high degree of resistance after a few weeks of growth. In our experimental trials we have always aimed to grow the seedlings on healthy soil, although under Wisconsin conditions the temperature is

[16] Tisdale, W. B. Influence of soil temperature and soil moisture on the occurrence of yellows in cabbage seedlings. In manuscript.

usually too low for infection to occur while seedlings are in this susceptible period. In certain sections of the country, however, cabbage seed is sown at a time when the soil temperature is near the optimum for infection by *Fusarium conglutinans*. For best success, therefore, it is essential to make the seed bed on healthy soil. Trials have been made of one or more of these resistant strains in so many other states that we feel confident in our conclusion that the resistant qualities will be maintained without serious impairment anywhere that the cabbage will succeed.

If these conclusions are correct, it would seem, therefore, that the only serious condition yet to be met is that of the commercial production and distribution of the different varieties of resistant seed suited to local needs.

Commercial Production and Distribution of Resistant Seed

As soon as the merits of the Wisconsin Hollander were established the question arose as to how best to insure the production and distribution of an adequate supply of reliable seed under commercial conditions. At the outset the aim was simply to meet the needs of the Wisconsin cabbage growers, especially in the Fusarium-infested regions of the southeastern counties. This was done by the selection, at a meeting of the leading growers of this section, of a committee of five men,[17] all experienced in handling cabbage. To them was entrusted the responsibility for leadership in growing and distributing the seed. To this committee we turned over enough mother seed of the best resistant Wisconsin Hollander to inaugurate their undertaking, and we have since continued to cooperate with them by supplying them with any improved strains as these have been secured and through assistance in selecting mother heads for their seed growing. (See Fig. 10.) Through this committee somewhat over 100 pounds of Wisconsin Hollander seed was grown and distributed in 1917 and this was increased to 800 pounds in 1918. Meanwhile local growers have been encouraged to save for home seed growing the best heads from their own fields, especially where the soil is "sick" enough to insure opportunity

[17] The membership of this committee is as follows: W. J. Hansche, A. J. Piper, and S. B. Walker of Racine; Henry Broesch and W. Thompson of Kenosha; W. J. Miller of Somers. W. J. Hansche was chosen chairman and inquiries as to available seed should be addressed to him (W. J. Hansche, R. F. D. 4, Racine, Wisconsin).

for selecting especially resistant plants. In these ways the local needs have been fairly well met. The demand has, however, continued to increase from other parts of Wisconsin and from other states. It was foreseen that this would soon lead to the introduction by commercial firms of seed grown elsewhere under the regular contract method. The seed trade secures most of its cabbage seed in this way from either of three sources, Long Island, the Puget Sound region in Washington, or Europe, es-

FIG. 10.—WISCONSIN HOLLANDER SEED HEADS

A farmer's plantation of Wisconsin Hollander seed heads in early spring, 1916. These were especially selected from "sick" soil in the fall of 1915, kept in a cool storage house over winter, and reset into the field for seed production in 1916. Grown by Henry Broesch, Kenosha, Wisconsin.

pecially Denmark and Holland. Since cabbage seed can be secured from these regions under contract more cheaply than it can be grown in Wisconsin it is evident that seed growing in Wisconsin on a permanent commercial scale can be encouraged only in case this method is essential for the maintenance of the disease-resistant quality in the seed. If it is demonstrated that Wisconsin grown seed is distinctly superior, it will command a sufficiently higher price to keep it on the market, otherwise the cheaper contract grown seed will ultimately replace it. Experiments were, therefore, inaugurated several years ago to determine the facts as to this matter. The most reliable

method followed by commercial seedsmen is to furnish the contract grower with the mother seed, this mother seed being secured each year from reliable sources. The essential question is, therefore, as follows: If resistant Wisconsin grown mother seed is placed for one generation in another region on non-infested soil, and a seed crop is thus secured without further selection, will such seed have lost appreciably in its disease resistant character?

The first trials for determining this were undertaken in the spring of 1915. Seed of one of the head strains of Wisconsin Hollander was sent to the Washington State Experiment Station located at Puyallup,[18] a duplicate sample of the same lot of seed being retained for later comparative trial. The seed developed from this in Washington was returned to us in the autumn of 1917 and introduced into our 1918 trial field. In addition a commercial firm secured in 1915 some Wisconsin Hollander seed which was placed under contract with a Puget Sound seed grower in 1916–17. This firm supplied us with a sample of their western grown seed for the trial. These two samples were placed on "sick" soil along with the other strains under trial in 1918 with the following results.

TABLE VIII.—SUMMARY OF 1918 TRIALS COMPARING WESTERN GROWN SEED OF WISCONSIN HOLLANDER WITH HOME GROWN.

Seed strain under trial	Amount yellows
	Per cent
Best strain Wisconsin Hollander seed grown in 1913 (VIIIa—25)	0.9
Average 5 selections made from progeny of this in 1916	0.0
Average 17 selections made from general fields W. H. in 1916	2.0
Puyallup grown seed, Wisconsin Hollander (VIIIa—15)	3.1
Sample of "mother seed" strain sent to Puyallup in 1915 for seed growing (VIIIa—15)	0.0
Commercial seedsman's Puget Sound grown seed of Wisconsin Hollander	7.0
Control: Hollander seed commercially imported	84.6

Trials of the same lot of commercial seedsman's grown Wisconsin Hollander were repeated in two plots at Racine in 1919. The results secured were as follows:

[18] This seed was grown at Puyallup under the supervision of Director W. A. Linklater and Prof. J. L. Stahl.

TABLE IX.—SUMMARY OF 1919 TRIALS COMPARING WESTERN GROWN SEED OF WISCONSIN HOLLANDER WITH HOME GROWN

Location of plot	Strain of cabbage	Per cent yellow	Per cent killed by yellows	Per cent living	Per cent headed
Drummond plot	Average 4 strains of Wisconsin grown Wisconsin Hollander......	40.6	3.6	94.1	70.8
	Western grown Wisconsin Hollander..............................	34.4	7.2	89.6	63.2
	Commercial Hollander.............	98.9	85.9	9.3	7.6
Broesch plot	Average 4 strains of Wisconsin grown Wisconsin Hollander......	75.4	11.9	85.3	49.6
	Western grown Wisconsin Hollander..............................	61.6	16.0	80.0	51.2
	Commercial Hollander.............	100.0	98.0	1.0	1.0

In 1919 the disease was severe and any sign of yellows on the plants was recorded. Thus a comparatively high percentage of disease is shown in column 1 even for the resistant strains. This condition usually occurs in a warm season like 1919, but, as previously noted, most of the resistant plants are scarcely checked by this slight attack while a large percentage of the commercial strain, when infected, dies before the end of the season. The percentage of plants killed by yellows and the percentage heading are therefore the best criteria for comparing the various strains.

From both the 1918 and 1919 figures it is evident that all of these strains of Wisconsin Hollander gave fairly good results as to Fusarium resistance. The 1918 results are the more significant and they show quite clearly that under the conditions of that trial the western grown seed was not quite so resistant as that grown in Wisconsin. Even in 1918, however, the western grown seed made a satisfactory showing and in the 1919 trial it proved practically equal to the average run of Wisconsin Hollander. It is to be remembered that in both seasons the trial was made on ''sicker'' soil than will commonly be used for commercial cabbage culture and therefore that the differences are more pronounced than would be evident in general field usage. Considering, therefore, the commercial advantages of growing contract seed in the intensive seed-growing districts we

are approving this method with certain reservations aiming to reduce the dangers inevitably inherent in the procedure.

The first of these dangers results from the fact that it seems inevitable that there is in all these resistant cabbage strains a tendency to progressive reversion with a consequent loss in disease resistance which can only be met by continued selection from plants grown on "sick" soil. The commercial seedsman who ignorantly or for other reasons neglects to recognize this principle may therefore fail to keep his strain up to standard. There is also always the possibility of seed admixture and of cross pollination from adjacent seed fields, both of which will require greater attention from the seedsmen and contract growers with such a strain as this than with the less specialized types.

To meet the situation with the Wisconsin Hollander we have continued to urge Wisconsin cabbage growers who have especially "sick" soil, and who have already learned how to select heads from their own fields for seed growing, to continue this practice. This will insure them at least enough seed for their own use and in certain cases they will have a surplus to sell to their neighbors or to seedsmen. Certain commercial seedsmen are already arranging to secure their "mother seed" of resistant strains from heads carefully selected from "sick" soil with regard both to disease resistance and type. We shall continue to cooperate with both local growers and seedsmen in the establishment of these practices on a sound basis.

With the kraut varieties it is more difficult for the ordinary Wisconsin grower to succeed in seed growing. One reason for this is that the earliness of maturity causes a much greater loss of heads during winter storage. The chief initial requests for this seed moreover have come not from the growers directly but from the kraut packers who, in general, purchase and distribute to the farmers the seed from which their cabbage is to be grown under contract. Most of the kraut manufacturers of the country are members of the National Kraut Packers' Association. Accordingly an arrangement has been made with this Association by which this Experiment Station and the Federal Bureau of Plant Industry have cooperated for the growing of resistant kraut seed. In this way a considerable quantity of Wisconsin All Seasons and some Wisconsin Brunswick will be available for distribution in 1921. Efforts will be made so to place this as to insure the use of as much of it as possible on "cabbage sick"

soil and so to provide as to insure the production of an adequate crop of seed annually hereafter.

It is believed that through the state and national institutions proceeding thus in cooperation with the Wisconsin cabbage growers' committee, with the National Kraut Packers' Association, and with such of the seed firms as are undertaking to handle the resistant seed, it will be possible to place the production and distribution of this seed upon a permanently reliable commercial basis. Evidence has already come to hand, however, that along with this legitimate trade development there will be some confusion through the offering of so-called disease-resistant seed of unknown origin by ignorant or unreliable dealers. Probably this is not a matter which need mislead any intelligent cabbage seed dealer or grower. In any case, it will be greatly minimized if all reliable dealers offering these Wisconsin strains of resistant seed will use the names herein given to them and will so state the source of their seed supply as to make clear the essential facts as to its origin or history.

SUMMARY AND CONCLUSIONS

1. The disease known as cabbage yellows, caused by the soil parasite *Fusarium conglutinans,* is widely distributed and seriously destructive in the United States.

2. Once introduced, it persists indefinitely in the soil and there is no known method of control except through the use of disease-resistant strains.

3. It has been found that of the commercial varieties the Volga is the most highly resistant and the Houser is somewhat resistant, but neither of these varieties meets important commercial needs.

4. The chief commercial cabbage industry in the sections where the yellows disease occurs is concerned with growing either a winter storage or shipping crop or a mid-season or autumn crop for kraut manufacture. To a lesser degree there is need for truck types.

5. Experience justifies the belief that these several needs can all be met by the selection of Fusarium-resistant strains from the standard commercial varieties now in use which are best adapted to these various purposes.

6. In undertaking such selection our first success was attained with the standard winter storage variety, Hollander or Danish

Ball Head. From this was developed the resistant strain known as Wisconsin Hollander. Since experience showed that an earlier strain of this was needed, further selection was made and a resistant strain secured which combines with earlier maturity a rounder head and shorter stem. This has been distributed under the name Early Wisconsin Hollander, and for purposes of distinction the original resistant strain is now being called Late Wisconsin Hollander.

7. In order to meet the needs of the kraut industry, resistant strains have been selected from two of the leading commercial kraut varieties, Brunswick and All Seasons, and these have been distributed under the names Wisconsin Brunswick and Wisconsin All Seasons.

8. Other Fusarium-resistant selections are receiving attention as follows: Professors White and Close of the Maryland Experiment Station have secured and distributed a resistant strain of the Late Flat Dutch; Professors Melhus and Gilman of the Iowa Experiment Station are developing a resistant Copenhagen Market. In Wisconsin the Experiment Station, in cooperation with the Bureau of Plant Industry of the U. S. Department of Agriculture, is working with resistant selections of All Head Early, Glory of Enkhuizen, and Copenhagen Market.

9. By following the proper methods any skillful cabbage grower who has Fusarium-sick soil may either undertake with reasonable confidence to develop a resistant strain of his own, or having secured one of these resistant strains he can maintain its resistance and produce his own seed.

10. It is, however, important to note that the Fusarium disease or yellows is often confused by growers with the bacterial black rot *(Bacterium campestre)*, and that these selected strains have not proved to be especially resistant to this nor to the other common cabbage diseases such as black leg (Phoma) and club root (Plasmodiophora).

11. In all cases the degree of resistance to Fusarium shown by these strains is relative, not absolute. The seedling plants are less highly resistant than they are after the transplanting stage.

12. Environmental factors, especially soil temperature, influence the development of the disease and also the disease resistance of the host. High soil temperature favors the disease and low temperature inhibits it. It does not develop even in the

non-resistant strains at a temperature below about 17°C. (62°F.) and at high soil temperatures even the most resistant strains show a considerable percentage of infection.

13. In accordance with the temperature relations noted above, the best results are obtained under Wisconsin climatic conditions by starting even the resistant strains in a non-infested seed bed to avoid possible seedling infection. These strains are then sufficiently resistant following transplantation to mature a commercially successful crop even on badly diseased soil.

14. These resistant strains have proved resistant so far as tested in other states. It seems probable that the only limitation in this respect which might occur would be in cases where they were subjected to more trying conditions as to soil temperature, especially in the seedling stage.

15. Should such conditions be met, our experience gives us confidence that through further selection resistant strains suited to any localized conditions could be secured. It is our belief, therefore, that the cabbage industry can be permanently maintained in any section of the country, in so far as the Fusarium or yellows disease is a limiting factor, through the selection of disease-resistant strains.

16. It seems probable that in case the resistant strains are propagated through successive generations without repeated selection, they will tend to lose to some extent the disease-resistant character.

17. When, therefore, it seems desirable for commercial purposes to grow the seed crop under contract in non-infested regions, it is urgently recommended that the mother seed for each such contract crop be secured from plants carefully selected for resistance and type from Fusarium infested fields. By this method it is believed that the present standards may be essentially maintained and seed successfully produced on any desired scale, by the commercial contract method.

18. Work on the disease-resistant cabbage strains will be continued by this Experiment Station in cooperation with the Bureau of Plant Industry of the U. S. Department of Agriculture and with certain other state experiment stations. While it will not be practicable for these institutions to grow or distribute seed other than for trial purposes, they will advise or cooperate with growers or seed firms in securing an adequate supply of resistant mother seed.

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Influence of Rations Restricted to the Oat Plant on Reproduction in Cattle

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Influence of Rations Restricted to the Oat Plant on Reproduction in Cattle

In 1911[1] the Wisconsin Experiment Station published data comparing the effect of rations balanced from the corn, oat, and wheat plants upon growth and reproduction in cattle. Rations restricted to the corn plant were highly successful for both growth and reproduction, while rations restricted to the wheat plant were disastrous to successful growth and reproduction. The work with a ration made from the oat plant indicated at that time that it was not possible to make a highly successful ration from rolled oats and oat straw. In 1917[2] further data were published bearing on the influence on growth and reproduction of nutrients derived from the corn and wheat plants. Evidence was reported fixing the responsibility for incompleteness of the ration made from the wheat plant upon (1) a poor mineral content and (2) inherent toxicity in the wheat kernel. In 1913[3] Power and Salway reported the isolation of choline from the wheat embryo, but whether this substance can be responsible for the bad effects observed at this Station with wheat grain feeding is an open question.

It is altogether possible that a third deficiency, namely, the fat soluble vitamine, is operative in a ration made exclusively from the wheat plant. Studies on the content of this nutritive factor in cereal straws are now under way. It will be recalled that successful reproduction with the wheat grain and wheat straw ration was secured only when part of the wheat straw was replaced by a good roughage such as alfalfa, but only for a single gestation. In the second gesta-

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[1] Hart, E. B., McCollum, E. V., Steenbock, H. and Humphrey, G. C. Physiological effect on growth and reproduction of rations balanced from restricted sources. Res. Bul. **17**, Wis. Agr. Exp. Sta. 1911.

[2] Hart, E. B., McCollum, E. V., Steenbock, H. and Humphrey, G. C. Physiological effect on growth and reproduction of rations balanced from restricted sources. Jour. Agr. Res. **10**: 4, 175. 1917.

[3] Power, F. B. and Salway, A. H. Chemical examination of wheat germ. Pharm. Jour. **91**: 117. 1913.

tion period the cumulative effect of the toxicity in the ration manifested itself in imperfect offspring. With corn stover replacing the wheat straw only partial success in reproduction was attained. The substitution of these roughages introduced into the ration primarily a better salt mixture, and probably also a greater supply of the fat soluble vitamine.

The work re-emphasized the complexity of the problem of the nutrition of herbivora and the limitations of the old views of a balanced ration. It expanded the ideas as to what must be the nutritive factors in a complete ration. It showed also that the same factors of nutrition operative in the life cycle of our most extensively investigated mammal, the rat, were also operative with this species. Studies on the causes of the deficiencies in the oat plant ration have been continued and the results of that work are incorporated in this publication.

Earlier investigation of the oat plant as the sole source of nutrients for cattle showed that it was possible to secure good growth, fair reproduction and milk secretion, but not the production of offspring of the highest degree of vigor. The calves born were not so strong and vigorous as those produced by cows fed a corn plant ration, yet the reproduction results secured at that time were much better than the reproduction results obtained on the wheat plant.

Present knowledge of the great importance of an adequate mineral supply in the ration and the deficiencies of grains and cereal straws in these respects, particularly in reference to calcium, sodium and chlorine, prompted a review of earlier work with the oat plant. The facts are that the oat straw used in those earlier experiments had been grown on an alkaline soil and contained .84 per cent of CaO. This amount of CaO compared favorably with the amount in the corn stover used at that time, which was .74 per cent. Sodium chloride need not be considered in these rations as it had always been fed generously to these animals. The superior results secured with the corn ration as compared with the oat ration, although the former contained slightly less calcium, must rest either upon the poorer availability of the calcium in the oat straw, or upon other factors more generously supplied by the corn stover. The latter view is more probable because we are inclined to believe that a more liberal supply of vitamines would accompany corn stover as

compared with well ripened oat straw. This higher content of calcium in the oat straw used in the earlier experiments is probably directly responsible for the mediocre calves produced in the earlier experiments with the oat plant.

In later work the oat straw used was much lower in mineral content than that used in the earlier experiments. It contained, in fact, but .47 per cent of CaO, or approximately one-half that of the straw used in the earlier work; and the calves were far inferior.

EXPERIMENTAL CONDITIONS

The cattle used for these experiments were grade Holstein heifers. They were brought into the experimental herd usually at the age of 16 to 20 months and ready for breeding. The herd was maintained free from tuberculosis and contagious abortion through tri-monthly inspections for tuberculosis and monthly inspections for contagious abortion by the Department of Veterinary Science of the University. These animals were kept in a well-lighted basement with access in fair weather to an outdoor paddock free from all vegetation. Earlier experience had shown that growth could be secured on a ration made up of 7 parts of rolled oats and 7 parts of oat straw, such as was used. Consequently, in most cases these rations were made up on the basis of equal parts of roughage to equal parts of grain or grain substitute. Offered in these proportions the cows were allowed all of the ration they would consume. The modification of the basal ration of 7 parts of oat straw and 7 parts of either whole oats or rolled oats was toward an improvement of the probable deficiencies in the known nutritive factors. They consisted of single or multiple additions of casein for the improvement of the proteins, of butter fat to increase the fat soluble vitamine content of the ration, and salts—particularly calcium salts—to make up deficiencies in this element. Sodium chloride was fed *ad libitum.*

THE EFFECT OF THE BASAL RATION ALONE

The effect of feeding the oat grain as rolled oats or ground oats plus the oat straw alone was invariably to produce a premature birth. The calf was born either dead or extremely

weak. Parturition was premature by two to three weeks and the mothers would fail to "clean" naturally.

Where the calves were born alive it was necessary to feed them from a bottle and even then they did not live. Their blat was feeble and the rate of respiration abnormally high. The mothers remained in only a fair condition on such a ration, as evidenced by the condition of the hair coat, but their live weight was maintained. Cows No. 661 and No. 648 illustrate these results. The calf (male) from 648 was born 17 days ahead of normal parturition time and weighed 47 pounds. The calf (male) from 661 was born 19 days ahead of time and weighed 67 pounds. Both were born dead. See figures 1 and 2.

THE EFFECT OF FORTIFYING THE OAT PLANT RATION WITH THE ADDITION OF EXTRA FAT SOLUBLE VITAMINE

The oat grain itself is not abundantly supplied with the fat soluble vitamine[4]. The actual content of oat straw in this nutritive factor is unknown. It would probably vary with the stage of cutting. The straw used was well matured. The absence or scarcity of this vitamine in the diet usually manifests itself in xerophthalmia, an inflammation of the conjunctiva, and edema of the eye lids; at least this is true of the rat, and similar observations have been made on the human infant[5] and the rabbit[6]. No indication of such a condition was manifested by these cattle. Although xerophthalmia does not invariably follow a deficiency of the fat soluble vitamine in the diet with all species, experiments were initiated where two pounds of butter fat were added to every 100 pounds of grain fed. This fat soluble vitamine addition alone did not improve the ration for reproduction. While it may have been one of the essential nutritive factors responsible for failure to secure optimum results, yet it was not the principal factor operative in the production of the poor offspring. The experience in these cases was not different from those with the grain and straw alone. Calves were born prematurely and were

[4] McCollum, E. V., Simmonds, N. and Pitz, W. The nature of the dietary deficiencies of the oat kernel. Jour. Biol. Chem. 29: 341. 1917.
[5] Block, C. E. Eye diseases and other disturbances in infants from deficiency of fat in the food. Ugeskruft. für Laeger. 68: 1516. 1917.
[6] Nelson, V. E. and Lamb, A. R. The effect of vitamine deficiency on various species of animals. Amer. Jour. Physiol. 51: 530. 1920.

either dead or extremely weak. The calf of cow No. 656 was born 19 days ahead of time, alive, but extremely weak. When picked up it hung from the arm as limp as a rag and died a few days after birth. It was a male and weighed 70 pounds.

The calf of cow No. 653 was born 23 days ahead of time and alive, but lived only a few days. It threw its head backward in a way similar to that of so many wheat calves. This is illustrated in the photographs. It also was a male and weighed 69 pounds. See figures 3 and 4.

THE EFFECT OF IMPROVING THE PROTEIN OF THE RATION BY SUPPLEMENTING WITH CASEIN

The fact that these animals grew very well on a ration composed of either equal parts of whole oats or of rolled oats and oat straw shows that the protein supplied was sufficient for cattle of this age. Data were secured, nevertheless, on the effect of improving the ration by the use of approximately 25 per cent of the protein as casein. The ration fed consisted of 6.7 parts of whole oats, 0.3 parts of casein and 7 parts of oat straw. The animals were given all they would consume of this ration, but in the proportions indicated. This improvement in the quality of the proteins of the ration had no ameliorating effects whatever on the character of the offspring produced by these cows. These results are shown in figures 5 and 6.

Cow No. 660 freshened 21 days ahead of time, giving birth to a 50-pound heifer calf. The calf was extremely weak, could not stand alone, was fed from a bottle and died after 24 hours. The cow was in poor condition and did not "clean" naturally. A duplication of this result was made by cow No. 670 on the same ration. This cow freshened 14 days ahead of time, giving birth to a 48-pound bull calf. It was born at 3 p. m., but could not stand at 10 a. m. the next day. It had a feeble blat, was nursed from a bottle and died at the end of 48 hours. The mother did not "clean" naturally, although she remained in fairly good condition during the gestation period. These results and those already described show that improvement of an oat plant ration could not be made through the use of more fat soluble vitamine or a better protein mixture alone.

THE EFFECT OF TWO ADDITIONS TO THE OAT PLANT RATION—FAT SOLUBLE VITAMINE AND CASEIN

Since the addition of a single nutritive factor such as the fat soluble vitamine or casein did not improve the oat plant ration for calf production the simultaneous addition of the two was next tried. This ration consisted of 6.7 parts of whole oats, 0.3 parts of casein and 7 parts of oat straw. To 100 pounds of the grain mixture there were added 2 pounds of butter fat. There was no apparent improvement in this ration for reproduction. Figures 7 and 8 illustrate this.

Cow No. 671 gave birth three weeks ahead of time to a 59-pound male, weak and unable to stand. It threw its head back upon its shoulders in very much the same way described for calves produced on the wheat ration and for the offspring of No. 653, figure 3. Like them, it died after a few days. It is a curious fact that the mammary glands of the cows fed these incomplete rations developed very rapidly—four to five days—immediately previous to parturition as contrasted with normal conditions of nutrition when the process is slow and gradual.

Cow No. 670 produced a 48-pound, dead male calf 26 days ahead of time. The mother did not "clean" naturally, but outwardly this cow remained in a fair state of nutrition.

THE EFFECT OF AN IMPROVEMENT IN THE MINERAL CONTENT OF THE RATION

The fact that improvement in the ration could not be made by the addition of the fat soluble vitamine alone, or by the addition of a better protein, or by a combination of the two, led to making additions of calcium salts. In earlier work it had been learned that by the addition of a complex salt mixture to a ration of corn grain, gluten feed and wheat straw[2], failure in reproduction could be changed into success. The materials used in that earlier work consisted of potassium, magnesium and calcium salts of organic acids, such as citric and lactic acids. From analysis of the oat plant ration and experience with laboratory animals it did not seem necessary to use a salt mixture as complex as the one used previously, and especially one con-

taining magnesium and potassium; consequently, calcium salts alone were used. Commercial sources were drawn upon for these materials. Calcium acetate—89 per cent, a by-product of the acetone industry; wood ashes—a complex salt mixture, 55 per cent of which was calcium carbonate; and finely ground rock phosphate—84 per cent calcium phosphate, tri-calcium—were used at the rate of 2 pounds to 100 pounds of grain or grain mixture. In some cases the calcium salts were used with casein or butter fat or both, but in other cases addition of calcium salts was the only supplement made to the oat plant ration, with the exception of common salt; this was given the animals twice weekly and amounted to about one ounce each time.

The results secured are exceedingly interesting and important in that they show that the chief deficiency in the oat plant ration was calcium. Since sodium chloride was always used in the ration there was no means of knowing whether or not this was present in insufficient amounts. If one can judge from mere gross examination it is doubtful if the offspring secured through either calcium additions alone or calcium additions plus casein or casein and butter fat were as vigorous as those produced where the oat straw was partly or wholly substituted by natural plant materials such as alfalfa, corn stover or clover hay; but we did secure active, healthy calves which could be successfully reared when the ration was supplemented with calcium salts. Figures 9, 10, 11, 12, and 13 illustrate the results obtained in this series.

Cow No. 676 received a ration of 7 parts of whole oats, 7 of oat straw and 2 pounds of wood ashes to 100 pounds of grain. She produced a 75-pound heifer calf which suckled the mother soon after birth. The calf was born 16 days ahead of time but appeared fairly strong. The mother remained in excellent condition but did not "clean" naturally at parturition. However, the after-birth came away with little difficulty.

Cow No. 668 received a ration of 7 parts of whole oats, 7 of oat straw and 2 pounds of calcium acetate to 100 pounds of grain plus common salt as in all cases. She freshened 7 days ahead of time, produced a 69-pound heifer cow which was apparently strong and vigorous. This cow "cleaned" naturally One of the noticeable effects of calcium additions to this ration

was to prolong the gestation period to its normal limit. Further, in nearly all of the cases of deficient rations, premature birth and retention of the placenta were generally synonymous.

Cow No. 660 received a ration of 6.7 parts of whole oats, 0.3 of casein, 7 of oat straw and 2 pounds of floats (crude calcium phosphate) to 100 pounds of grain. Notice in figure 5 her record where no calcium salts were added in the gestation period immediately preceding this one. In this gestation period with calcium addition she produced a 65-pound heifer calf of fair strength which was born 8 days ahead of time. This cow ''cleaned'' naturally. From the appearance of the hair coat she was not in first class condition, but apparently this did not indicate a status of malnutrition of a degree sufficient to interfere with normal reproduction.

Cow No. 656 received a ration of 7 parts of whole oats, 7 of oat straw, 2 pounds of butter fat and 2 pounds of calcium acetate to 100 pounds of grain. Notice her record in the preceding gestation, figure 4. She now produced a 64-pound heifer calf 6 days ahead of time. The calf was small but fairly strong. The cow ''cleaned'' naturally. The calf suckled the mother for 4 days, after which it was transferred to separator skimmilk. This milk was the product of the University herd in March, 1918. On this milk the calf grew 48 pounds in 50 days and appeared in thrifty condition. Starch, equal to the heat value of the fat removed had been added to the skimmilk. These facts are somewhat irrelevant to the matter in hand but do show two things: first, that this calf could be raised; and second, that separator skimmilk probably contains enough of the fat soluble vitamine for the early growth of calves.

Cow No. 671 received a ration consisting of 6.7 parts of whole oats, 0.3 parts of casein, 7 parts of oat straw, 2 pounds of butter fat and 2 pounds of wood ashes to 100 pounds of grain mixture. On this ration she produced a 74-pound male of fair vigor. The calf was born 12 days ahead of time, suckled the mother without help and was reared. This cow ''cleaned'' naturally. Contrast this record with that of the preceding gestation period, involving the absence of calcium salts as a supplement and shown in figure 8.

These five positive results on the influence of calcium additions make it clear wherein rested the main deficiency in the

oat plant ration used in this work. Variations in the calcium content of straw will occur, depending upon the soils producing them. This statement is equally true of other plant stems and leaves (roughages), but limited, of course, with respect to the lower and upper level of calcium content fixed by the species themselves. Legume hays as alfalfa or clover, if they can be grown at all, will probably never be so low in calcium content as a cereal straw or some of the grasses.

Effect of Natural Plant Materials as Partial or Complete Substitutes for the Oat Straw

It became imperative to obtain definite information as to what natural roughages could partly or wholly replace the straw and be effective for reproduction. Corn silage was first used allowing 12 pounds of this material to replace half of the oat straw, when expressed in terms of dry matter. The ration consisted of 7 parts of whole oats, 3.5 of oat straw and 12 of corn silage. The silage contained .25 per cent of CaO. On the basis of 7 pounds of air dried roughage the 3.5 pounds of oat straw and 12 pounds of silage would be equivalent to a roughage containing .66 per cent of CaO. On this ration varied results were obtained. It seemed to be dangerously near the lowest limit of calcium allowable for successful reproduction in this class of animals. The results are illustrated in figures 14 and 15.

Cow No. 656 produced on this ration a 73-pound heifer calf born 6 days ahead of normal time. This calf was strong and vigorous. The cow remained in splendid condition and "cleaned" naturally. This reproduction was both normal and satisfactory.

Cow. No. 653, receiving the same ration, produced an apparently strong, active male calf of 73 pounds weight 11 days ahead of time. The calf appeared thrifty at birth, but at the end of 24 hours began to grow weak and at 48 hours was dead. The cause of death was unknown. The cow did not "clean" naturally, although she appeared in good condition throughout the entire gestation period. It is evident that the ration was not in optimum balance for all individuals.

Displacement of part of the oat straw with a calcium-rich legume hay was next tried. The ration consisted of 7 parts of

whole oats, 4 of oat straw and 3 of alfalfa. The alfalfa contained 2.12 per cent of calcium oxide. This was equivalent to the use of 7 pounds of roughage with a calcium oxide content of 1.18 per cent, or two and a half times that of an equivalent of oat straw. The results are shown in figures 16 and 17. Cow 655 produced an 84-pound male calf 5 days ahead of time. The calf was strong and lived. The cow was in splendid condition and "cleaned" naturally.

A duplicate of this performance was made by cow No. 657. She produced an 80-pound male calf born but 3 days ahead of time. This cow also "cleaned" naturally and was in a fine state of vigor throughout the entire gestation period. Where successful nutrition was established, as in these cases, there was a gradual but progressive udder development rather than the sudden enlargement of the mamma as seen so often in cases of restricted and inefficient rations.

The calves produced by these cows, as well as those to be described hereafter, were sturdy and vigorous and generally of greater weight than those produced on the oat-straw, oat grain ration with calcium salt additions. This experience would indicate that the natural and better roughages were making the ration a more complete one than the additions of known substances had succeeded in doing. While a great deal was accomplished by rebuilding the oat plant ration through protein, fat soluble vitamine and especially calcium additions, yet for most excellent results in reproduction it would probably be preferable to substitute a part of the straw for a higher calcium containing roughage rather than to rely on the addition of calcium salts alone. These results also have great practical application. They show how it is possible to use a straw in a ration with greatest success.

Where corn stover completely replaced the oat straw, successful reproduction was had. The ration consisted of 7 parts of whole oats and 7 parts of corn stover. This corn stover contained .75 per cent of calcium oxide. The results secured are shown in figures 18, 19 and 20. On this ration cow No. 659 freshened in August, 1917, 15 days ahead of time. The calf was a 66-pound male. It was weak at birth, but grew stronger and lived. The cow did not "clean" naturally. She was continued on the same ration for another gestation period, using the same

roughage. In August, 1918, she produced a 65-pound heifer calf 13 days ahead of time. This calf was strong at birth, on its feet suckling half an hour after being born and was successfully raised. The cow ''cleaned'' naturally.

Cow No. 662 on the same ration freshened 10 days ahead of time, producing an active and vigorous 64-pound heifer which was raised successfully. The placenta was expelled without help.

In figures 21 and 22 are shown the records of reproduction with whole oats and clover hay, or part clover hay. When all of the oat straw was replaced by medium red clover hay with a calcium oxide content of 1.48 per cent a successful life cycle was secured. Cow No. 680, purchased as a heifer of 300 pounds weight had matured on this ration and in October, 1918, gave birth to a 94-pound strong, male calf. The calf remained strong and was reared. There was no retention of the afterbirth. Where clover hay replaced 2 parts of the oat straw and corn stover replaced 5 parts of the straw, successful reproduction was secured. This mixture of 2 parts of clover hay and 5 parts of corn stover gave a roughage of .96 per cent of calcium oxide.

On this ration cow No. 671 produced a 90-pound heifer calf 2 days ahead of time. The calf was strong and thrifty and in fine condition. The cow ''cleaned'' naturally. Contrast this record with that shown by this same cow in figures 8 and 13. On an oat ration without calcium additions she produced a weak 59-pound calf that died. On the same ration, plus calcium salts as wood ashes, she produced a fairly strong 74-pound calf that was successfully raised. On the oat grain plus clover hay and corn stover she produced a 90-pound calf which was also strong and vigorous.

Much prejudice exists against wild marsh hay as a roughage. This is probably because our judgment of the value of a roughage has been guided by its content of protein, or carbohydrate, or ether extract. While for certain purposes the protein content of the roughage is of great importance, yet for reproduction and normal physiological performance the special value of a roughage when fed with a grain will depend upon its vitamine and mineral content, particularly calcium. Marsh grasses, like other grasses, will vary in their mineral content, depending up-

on the soil on which they are grown. In the particular experiments reported here a marsh hay grown on the alkaline marsh soil owned by the University was used. The soil itself was rich in lime as evidenced by the shell deposits found in it. This wild marsh hay in its air dried condition contained 1.18 per cent of calcium oxide. This hay was used as a complete substitute for oat straw. Our ration consisted of 7 parts of whole oats and 7 parts of marsh hay. This ration was fed continuously and in an air dried condition during the entire gestation period. Further, common salt was always allowed all of these animals. Figures 23 and 24 illustrate the results. Splendid offspring resulted showing that a marsh hay grown on an alkaline marsh may become a very useful roughage. Such results may not be secured when the hay is cut from an acid marsh.

Cow No. 659 produced an 84-pound male calf freshening 14 days ahead of time. The calf was strong and active and was successfully raised. The cow remained in splendid condition. The afterbirth came away naturally.

Cow No. 662 on the same ration produced a 91-pound male calf, also strong and active. This cow continued in vigorous condition during the entire gestation period and "cleaned" naturally.

A summary of the most important data relating to these experiments is presented in Table I. Particular attention should be given to the fairly close correlation between the calcium content of these rations and successful reproduction.

GENERAL DISCUSSION

The results of this inquiry into the deficiencies of the oat plant for successful reproduction in cattle, point toward the inorganic constituents as the one of first importance. The results also make calcium the principal deficiency where common salt is added to the ration as is customary. Our data indicate that when other factors are adequately supplied, the ration of an herbivorous animal should contain at least .45 per rent of calcium oxide calculated on the basis of the total ration. An air dried roughage containing 0.9 per cent of calcium oxide, provided it were fed as half of the dry matter of the ration, would probably be adequate in calcium oxide content.

TABLE 1.—DATA ON THE NATURE AND CALCIUM CONTENT OF THE RATION AND CONDITION OF THE OFFSPRING AND COW

Cow No.	Ration Lbs.	Per cent CaO in ration	Weight of calf Lbs.	Condition of calf at birth	Removal or retention of placenta
648	7 whole oats 7 oat straw	.31	47	Dead	Retained
668	7 whole oats 7 oat straw	.31	67	Died shortly after birth	Retained
656	7 whole oats 7 oat straw 2 lbs. butter fat per 100 lbs. grain	.31	70	Weak, died in 48 hours	Retained
653	7 whole oats 7 oat straw 2 lbs. butter fat per 100 lbs. grain	.31	69	Weak, died in 72 hours	Retained
660	6.7 whole oats .3 casein 7 oat straw	,31	50	Weak, died in 24 hours	Retained
670	6.7 whole oats .3 casein 7 oat straw	.31	48	Weak, died in 48 hours	Retained
671	6.7 whole oats .3 casein 7 oat straw 2 lbs. butter fat per 100 lbs. grain	.31	59	Weak, died	Retained and "cleaned" with difficulty
670	6.7 whole oats .3 casein 7 oat straw 2 lbs. butter fat per 100 lbs. grain	.31	48	Dead	Retained
676	7 whole oats 7 oat straw 2 lbs. wood ashes per 100 lbs. grain	.62	75	Strong (fairly so)	Retained, but "cleaned" with ease
668	7 whole oats 7 oat straw 2 lbs. calcium acetate per 100 lbs. grain	.62	69	Strong	"Cleaned" naturally
660	6.7 oats .3 casein 7.0 oat straw 2 lbs. floats per 100 lbs. grain	.75	65	Strong (fairly so)	"Cleaned" naturally
656	7.0 oats 7.0 oat straw 2 lbs. calcium acetate 2 lbs. butter fat per 100 lbs. grain	.62	64	Strong (fairly so)	"Cleaned" naturally
671	6.7 oats .3 casein 7.0 oat straw 2 lbs. butter fat 2 lbs. wood ashes per 100 lbs. grain	.62	74	Strong (fairly so)	"Cleaned" naturally
656	7.9 oats 3.5 oat straw 12 silage	.41	73	Strong (fairly so)	"Cleaned" naturally

TABLE 1.—DATA ON THE NATURE AND CALCIUM CONTENT OF THE RATION AND CONDITION OF THE OFFSPRING AND COW—Continued

Cow No.	Ration Lbs.	Per cent CaO in ration	Weight of calf Lbs.	Condition of calf at birth	Removal or retention of placenta
653	7.0 oats 3.5 oat straw 12 silage	.41	73	Weak, dead after 48 hours	Retained
655	7.0 oats 4 oat straw 3 alfalfa hay	.64	84	Strong	"Cleaned"
657	7 oats 4 oat straw 3 alfalfa hay	.64	80	Strong	"Cleaned"
659	7 oats 7 corn stover	.45	66	Weak at first, grew strong	Retained
659	7 oats 7 corn stover	.45	65	Strong	"Cleaned"
662	7 oats 7 corn stover	.45	64	Strong	"Cleaned"
680	7 oats 7 clover hay	.80	94	Strong	"Cleaned"
671	7 oats 2 clover hay 5 corn stover	.50	90	Strong	"Cleaned"
659	7 oats 7 marsh hay	.61	84	Strong	"Cleaned"
662	7 oats 7 marsh hay	.61	91	Strong	"Cleaned"

It should be clear, however, that an optimum performance was never reached with our "synthetic" ration where more fat soluble vitamine and better proteins and calcium salts were added to our oat plant ration. A complete failure was transformed to a fair success, but not to a superlative one. The calves produced on the synthetic ration were not so sturdy as those produced from a high calcium natural roughage used as a supplement to the oat grain. Further, it appeared that success was as great with the oat plant ration supplemented with calcium salts and sodium chloride alone as where further additions of protein or fat soluble vitamine were made. This makes it clear that the main deficiency of the oat plant ration was a low calcium content.

Further, it is altogether possible that the calcium oxide figure advised as a minimum amount allowable in the ration of reproducing cows may be modified if the material were fresh,

green plant tissue and not dried. On this point there are no data at present.

Just why a low calcium intake should be the determining factor in normal or abnormal reproduction is not clear. The hypothesis[7] has already been offered "that with a generous sodium chloride intake and a low amount of calcium salts the surface protoplasmic films of the epithelial cells of the intestinal mucosa would present a structure in which water was the continuous phase. This latter system would be one of greater permeability to water and water soluble substances. This hypothesis of intestinal protoplasmic structure as influenced by the balance of sodium and calcium salts in the ration would pave the way for the view that on low calcium rations there can be especially favorable conditions for continual absorption of products of intestinal origin, among which may be bacterial toxins or amines."

The foregoing hypothesis was outlined as a suggested explanation of unsuccessful reproduction with swine confined to grain diets, common salt and natural water. With swine, as with cattle, complete restoration to normal reproduction was established when a calcium rich legume hay, such as dry alfalfa, was incorporated in the ration. In the case of swine the factors introduced by the use of alfalfa hay have not been dissected and it can only be suggested, from analogy with the present experiments on cattle, that the main factor is a calcium factor. The work on the dissection of these facts, however, is in progress. We can see no reason why the foregoing hypothesis should not apply with equal force to the work with cattle. But there may be additional factors operative in this problem. Is there some accessory food factor (vitamine), concerned with calcium assimilation and possibly other physiological functions, in too low a supply in such cereal straws as here used so that when the ration is fortified with an extra supply of calcium salts the mass action of the latter becomes an effective means of assisting in calcium assimilation? Forbes[8] and Meigs[9] have observed that

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[7] Hart, E. B. and Steenbock, H. Maintenance and reproduction with grains and grain products as the sole diet. Jour. Biol. Chem. **39**: 209. 1919.

[8] Forbes, E. B. The mineral metabolism of the milch cow. Buls. **295**, **308** **330**. Ohio Agr. Exp. Sta. 1916–1918.

[9] Meigs, E. B., Blatherwick, N. R. and Cary, C. A. Contributions to the physiology of phosphorus and calcium metabolism as related to milk secretion. Jour. Biol. Chem. **37**: 45. 1919; **40**: 469. 1919.

milking cows are in negative calcium balance even with high calcium-containing rations, such as those containing dry alfalfa hay. Earlier observation at this Station[10] showed the same situation with oat straw as a roughage for both cows and goats. Would this be the case with green alfalfa hay or green oat hay? The extra drain put upon an accessory factor controlling calcium metabolism by a milking animal would be much greater than by a dry animal, by virture of the probable secretion of such a vitamine into the milk. We had no trouble with reproduction from dry cows where corn stover, clover hay, alfalfa hay or marsh hay was used as the roughage, although judging from the work of Forbes, Meigs and their associates these cows would very probably have been in negative calcium balance had they been milking. This may, however, depend upon the quantity of milk secreted. In the case of dry cereal straw with a low supply of calcium and presumably a comparatively low supply of an accessory factor influencing calcium assimilation, negative calcium balance would probably have prevailed even when the animals were not milking. If this hypothesis is tenable, then a ration made from the green oat plant would probably be adequate for a reproducing cow judged from the standpoint of calcium assimilation. This hypothesis would involve the assumption that green plant tissue was more abundantly supplied with a vitamine (anti-rachitic) controlling calcium assimilation than the dry material. All of these assumptions are subject to experimental inquiry.

During the course of this experiment on cattle many calcium determinations in the plasma of the blood were made. There is a remarkable constancy in the amount of this element circulating in the blood no matter whether the ration was especially low or especially rich in calcium. Variations are as great among individuals on the same rations as on rations high and low in calcium. A limited, but representative amount of data on this problem is shown in Table 2. These samples of blood were taken five months after the animals were put on their respective rations.

Two animals, Nos. 666 and 667, are included to show the con-

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[10] Hart, E. B., McCollum, E. V. and Humphrey, G. C. Rôle of the ash constituents of wheat bran in the metabolism of herbivora. Res. Bul. 5, Wis. Agr. Exp. Sta. 1909.

Steenbock, H. and Hart, E. B. Influence of function on the lime requirement of animals. Jour. Biol. Chem. 14: 59. 1913.

stancy of the calcium content of the blood as well as variations among individuals. These animals received nothing but alfalfa hay, the calcium oxide content of which was 2.12 per cent. These results on the calcium content of the blood plasma of cattle are in harmony with those reported by Meigs, Blatherwick and Cary,[11] but where a constant calcium intake was maintained. Apparently some mechanism is at work whereby during calcium scarcity in the ration or faulty calcium assimilation the skeletal tissue becomes a means for maintaining the blood composition constant. An over-abundance of calcium in the diet of this species apparently does not influence the concentration of calcium in the blood.

Table 2.—The Effect of Variable Amounts of Calcium in the Ration of Cattle on the Calcium Content of the Blood

Cow No.	Ration Lbs.	Mg. Ca in 100 cc. blood plasma
668	7 whole oats 7 oat straw	9.4
660	6.7 whole oats .3 casein 7.0 oat straw	9.6
660	Same + 2 lbs. crude rock phosphate per 100 lbs. grain	9.2
671	Same + butter fat + 2 lbs. wood ashes per 100 lbs. grain	9.2
680	7 whole oats 7 oat straw	11.6
667	Alfalfa	9.2
666	Alfalfa	11.6
659	7 whole oats 7 marsh hay	9.2
673	7 whole oats 7 oat straw + 2 lbs. Ca acetate per 100 lbs. grain	10.9

That raised the question whether or not the calcium content of the blood of these animals might be appreciably lower just prior to parturition—the period of most rapid foetus development. Such a condition on a low injestion of calcium might lead to serious disturbances such as have been noted in imma-

[11] Meigs, E. B., Blatherwick, N. R. and Cary, C. A. Contributions to the physiology of phosphorus and calcium metabolism of dairy cows. Jour. Biol. Chem. **40**: 469. 1919.

ture calf production. The data obtained here are very incomplete on this point and would not support such a view.

Cow No. 660 on a ration of 6.7 parts of whole oats, .3 of casein and 7 of oat straw showed 8.9 mg. of calcium to 100 cc of plasma one month before calving. At the end of five months of pregnancy the calcium content of her blood was 9.6 mg.

Cow No. 680 on a ration of whole oats and oat straw showed one month before parturition 10.8 mg. of calcium to 100 cc of blood plasma while at the end of five months pregnancy her blood contained 11.6 mgs. No positive significance can be attached to these limited data.

Certainly, further studies should be directed toward a thorough analysis of the blood stream of these animals at different stages of pregnancy, making organic as well as inorganic dissections with the hope of unraveling the causes of such marked disturbances in reproduction as are observed. The carbon dioxide combining power of the blood plasma of cows on oat straw and oat grain was not lower than that of cows restricted wholly to a plant material rich in bases, particularly calcium, such as alfalfa hay. In the case of cow No. 661, confined to a ration of oat grain and oat straw and giving birth to a weak calf, the alkaline reserve after five months' confinement to the ration was 61.8 to 100 cc of blood plasma.

Cow No. 666, receiving nothing but alfalfa hay during an entire gestation period and giving birth to a strong calf, showed an alkaline reserve of 61.4 to 100 cc of blood plasma after five months' restriction to the ration.

The evidence probably is against the idea that those rations producing weak offspring were rations that tended toward the production of a condition of acidosis.

In a practical way the results of this investigation must have great significance. They emphasize, far beyond its net energy and protein content, the dominating importance of forage for breeding animals and the necessity for emphasis upon the production and special selection of such forage. These results raise new questions in agriculture. Can safe forage of all kinds be grown on acid soils or will we find those types of plants naturally rich in calcium the most desirable ones to raise on such areas? Will timothy and other grasses and even corn stover be too poor in calcium content when grown on acid soils to

make possible the greatest efficiency in animal husbandry, or must we insist that for success in animal production the plants naturally rich in calcium, as legume hays, must be grown when a system of animal husbandry prevails and soils are acid? And again, will the calcium of materials in their green state, although they are percentagely poor in this element, be more completely assimilated than when the plant tissues are old and dried? These are problems for the future.

The results secured thus far do show very positively that a certain amount of poor roughage such as oat straw can be used with safety in the ration when the remainder of the roughage is drawn from a type rich in calcium.

SUMMARY

This publication embraces further work on the influence of restricted rations on reproduction in cattle.

1. A ration made from the oat plant was inadequate for efficient nutrition of breeding cows. The offspring were born prematurely and were either very weak at birth or born dead.

2. Additions of the fat soluble vitamine or of casein or of both of these nutritive factors to a whole oat, oat-straw ration did not improve it for reproduction.

3. Fortification of the oat plant with calcium salts either as a carbonate (wood ashes), as a phosphate (floats) or as calcium acetate greatly improved conditions for reproduction. Sodium chloride was always allowed. Under the influence of these additions, offspring of fair vigor were produced. This improvement in the ration was secured even without the addition of a better protein or more fat soluble vitamine to the oat grain-oat straw ration.

4. The "synthetic ration" apparently did not secure as strong offspring as were produced by the use of natural roughages such as corn stover, clover, alfalfa or marsh hay. The latter was grown on an alkaline marsh and gave surprisingly good results.

5. It would appear from these data that the ration of a dry breeding cow, where all other nutritive factors are satisfied, should contain at least, .45 per cent of calcium oxide. This

figure may not apply to a ration containing some fresh, green materials.

6. Brief presentation is made of an hypothesis explaining the results secured with suggestions for future work. Furthermore, attention is called to the practical significance of these studies as relating particularly to forage and acid soils.

Fig. 1. Cow No. 648 and her calf. Illustrates how disaster in reproduction will follow the continuous use of a ration of ground oats and oat straw in the proportion of 1:1. Too poor mineral content of the straw was the primary cause of this result.

Fig. 2. Cow No. 661 and her calf. Fed the same ration as 1 with a similar result.

Fig. 3. Cow No. 653 and her calf. Fed a ration of ground oats and oat straw—2 pounds of butter fat per 100 pounds of grain. Dead or weak calves were produced. The addition of more fat soluble vitamine did not, as a single addition, improve this ration for reproduction.

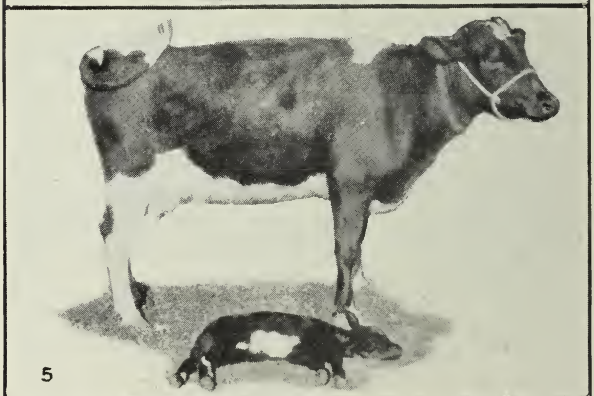


Fig. 4. Cow No. 656 and her calf. Fed the same ration as 1 with results of a similar character. Note deflection of the head and neck in both these cases.

Fig. 5. Cow No. 660 and her calf. Improving the oat plant ration with casein addition did not prevent disaster in reproduction. The ration fed consisted of 6.7 parts of ground oats, 0.3 parts of casein and 7 parts of oat straw.

Fig. 6. Cow No. 670 and her calf. The ration fed was a duplicate of that used for No. 660 and the results were of the same order. Weak, premature calves were born in both cases.

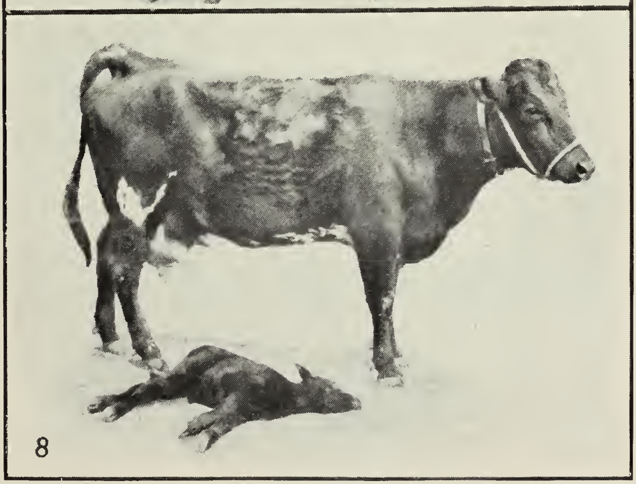
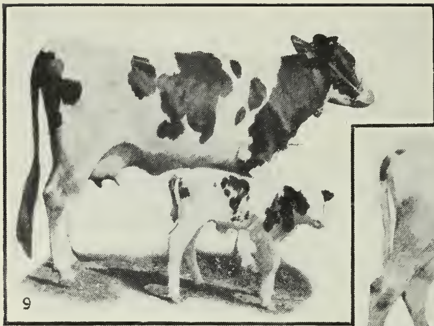
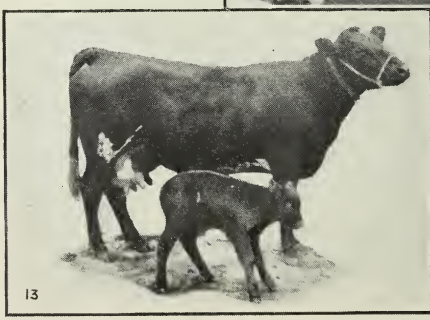


Fig. 7. Showing the effect of the addition of both casein and butter fat to a ration made from the oat plant. The two improvements were ineffective in making the ration a suitable one for reproduction. Cow No. 670 received 6.7 parts of ground oats, 0.3 parts of casein, 7 parts of oat straw and 2 pounds of butter fat to 100 pounds of grain. The calf was born dead.

Fig. 8. A duplicate of preceeding both in ration and results. Cow No. 671. The calf was extremely weak.





The effect of calcium additions to the oat plant ration.

Fig. 9. Cow No. 676 and her calf. She received a ration of 7 parts of ground oats, 7 parts of oat straw and 2 pounds of wood ashes per 100 pounds of grain. A successful reproduction resulted.

Fig. 10. Cow No. 668 and her calf. She received a ration of 7 parts of ground oats, 7 parts of oat straw—2 pounds of calcium acetate to 100 pounds of grain. Another successful reproduction.

Fig. 11. Cow No. 660 and her calf. This animal received a ration of 6.7 parts of whole oats, 0.3 parts of casein, 7 parts of oat straw and 2 pounds of ground rock phosphate to 100 pounds of grain. A fairly successful reproduction. Note the record of this same cow in 5.

Fig. 12. Cow No. 656 and her calf. She received 7 parts of whole oats, 7 parts of oat straw, 2 pounds of butter fat and 2 pounds of calcium acetate to 100 pounds of grain. A fair success in reproduction resulted. Note the record of this cow in 4.

Fig. 13. Cow No. 671 and her calf. She received a ration of 6.7 parts whole oats, 0.3 parts of casein, 7 parts of oat straw, 2 pounds of butter fat and 2 pounds of wood ashes to 100 pounds of grain. A fairly strong calf was produced. Contrast this record with the record of this cow in 8.

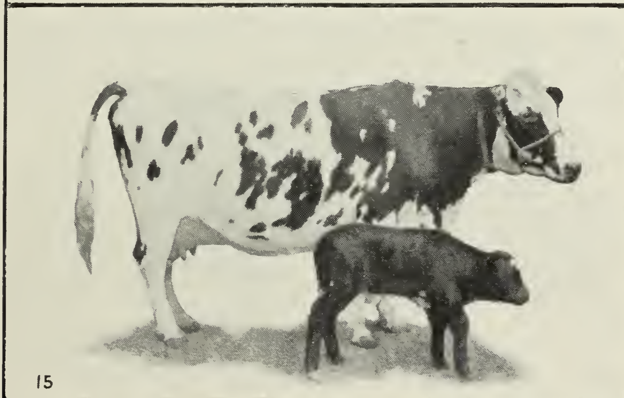
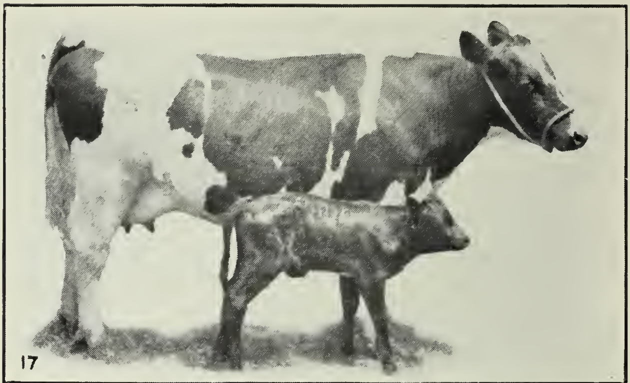
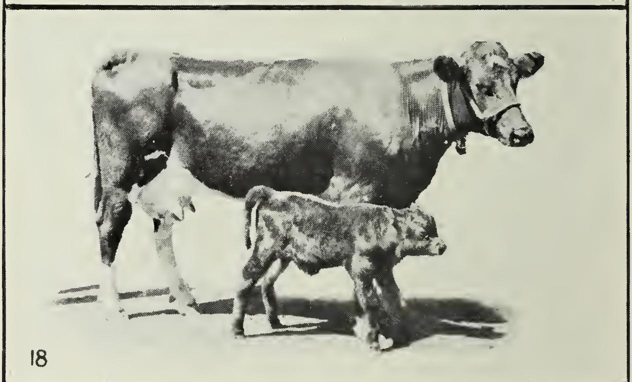


Fig. 14. Effect on reproduction of substituting corn silage for part of the oat straw. Cow No. 656 received a ration of 7 parts of whole oats, 3.5 parts of oat straw and 12 parts of corn silage. A strong, vigorous calf resulted.

Fig. 15. A duplicate of preceeding. Cow No. 653 on the same ration produced a thrifty, strong calf, but the cow did not "clean" naturally. These rations were probably dangerously near the lowest limit of mineral intake possible for successful reproduction.

Fig. 16. Effect of substituting alfalfa hay for part of oat straw. Cow No. 655 produced a strong 84-pound calf on a ration consisting of 7 parts of whole oats, 4 parts of oats straw and 3 parts of alfalfa.





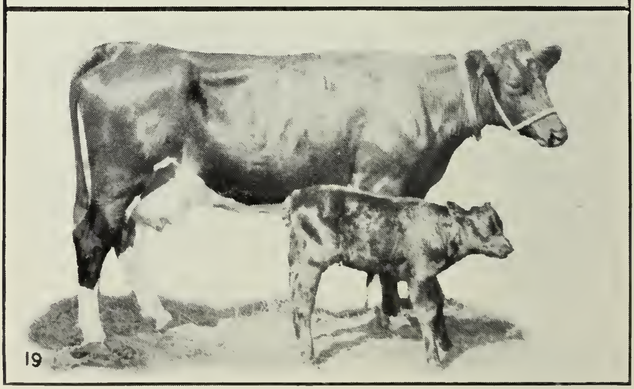
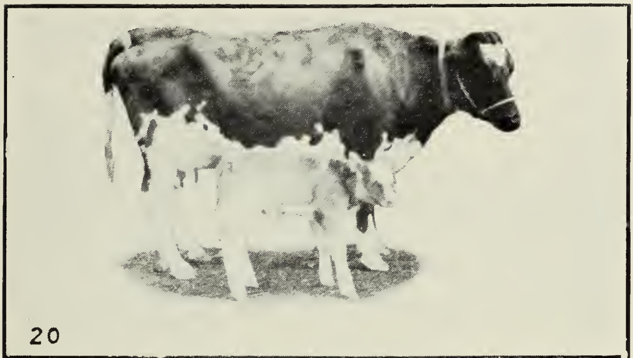


Fig. 17. The record of cow No. 657 is a duplicate in ration and result of 16. A strong 80-pound calf resulted; both cows "cleaned" naturally.

Complete displacement of the oat straw with corn stover results in successful reproduction.

Fig. 18. Cow No. 659 on a ration of 7 parts of whole oats and 7 parts of corn stover produced a calf of fair vigor in the first gestation period.

Fig. 19. In the second gestation period cow No. 659 produced a very strong calf with the same ration.



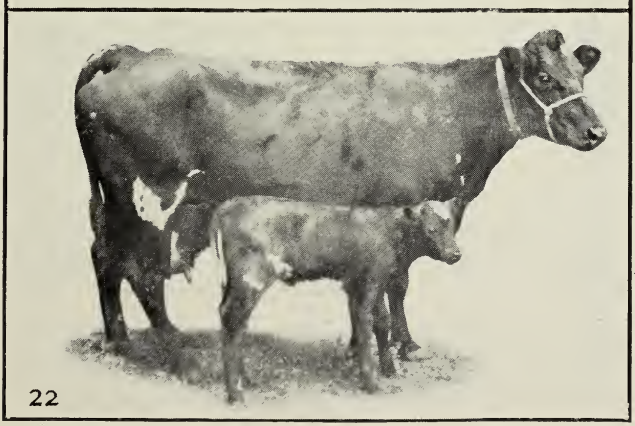
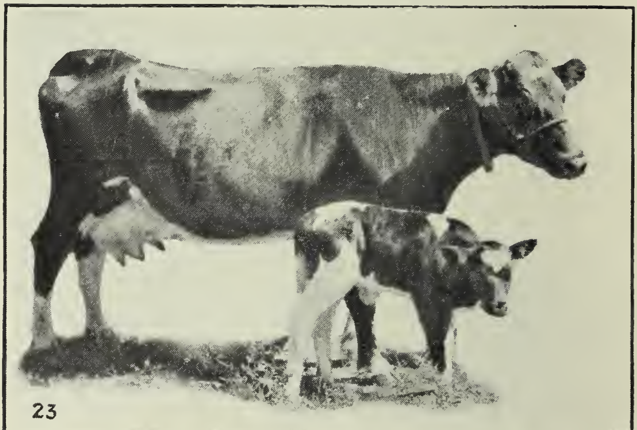


Fig. 20. A duplication of 18 and 19. Cow No. 662 likewise produced a strong offspring on this ration of whole oats and corn stover.

Complete displacement of oat straw with clover hay was very successful.

Fig. 21. Cow No. 680 produced a 94-pound, strong, male calf on a ration of 7 parts of ground oats and 7 parts of clover hay.

Fig. 22. Cow No. 671 and calf. On a ration of 7 parts of whole oats, 2 parts of clover hay and 5 parts of corn stover a very successful reproduction followed.



Marsh hay as a successful roughage and substitute for oat straw. The hay was grown on an alkaline marsh.

Fig. 23. Cow No. 659 and calf. A record of reproduction on a ration of 7 parts of whole oats and 7 parts of marsh hay.

Fig. 24. Duplicate of preceeding. Cow No. 662 on the same ration also produced a strong, vigorous calf. Both cows "cleaned" naturally.

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Pump Drainage of the University of Wisconsin Marsh

G. R. B. ELLIOTT, E. R. JONES and O. R. ZEASMAN

AGRICULTURAL EXPERIMENT STATION
OF THE UNIVERSITY OF WISCONSIN

CONTENTS

Pump Drainage of the University of Wisconsin Marsh

G. R. B. Elliott, E. R. Jones and O. R. Zeasman

The farm of the Agricultural Experiment Station of the University of Wisconsin contains about 130 acres of low land adjacent to Lake Mendota. The surface of nearly 80 acres of this is lower than the lake. In 1910 this surface was level with the lake, rising and falling as the lake rose and fell. It was a "floating" bog or a "lake-level" marsh.

Since then, all but about 5 acres left for comparison has been tile drained. An electrically driven, automatically controlled pump, lifting water 7 feet out of a reservoir into the lake, furnishes the outlet. Lines of tile generally 4 rods apart, from 3 to 5 feet deep, and discharging into mains that lead to the reservoir, effect the internal drainage. A turnpike along the lake acts as a dike to keep back the lake water. A ditch and a dike surrounding the low area act like an eave trough to catch the surface water from the surrounding hills and carry it to the lake without pumping. This diversion ditch is to protect the area so that only the seepage from the hills and the lake and the rainfall normal to the tract has to be pumped.

FIG. 1.—FROM CAT-TAILS TO CORN.

The marsh on the right of the ditch shows its original condition.

The area is a true peat bog of the alkaline type. The peat is from .1 to 6 feet deep and lies on a thin bed of marl which in places blends into silt or clay, varying in thickness up to 18 inches. Beneath the silt or clay is water-bearing sand in some places interbedded or intimately mixed with shell marl. So great was the artesian pressure in this sand that water would rise in a pipe 2 feet or more above the surface of the marsh.

The drainage of this marsh was started in 1910. This is a report of the experience of ten years that has resulted in the present drainage system. The drainage is now such that good crops of corn, buckwheat, timothy and alsike are harvested even in wet years.

FIG. 2.—HOW THE MARSH LOOKS

About 80 acres of the drained portion of the marsh is shown, crops of 1920. The lake is immediately beyond the row of willow trees in the background.

OPEN DITCHES FAILED

This tract has given us a splendid opportunity to carry on experimental work in drainage. A record of the mistakes as well as successes is worth reading from the experimental point of view. In 1910, open ditches were dug 16 rods apart over about 80 acres. They were 1 foot wide at the bottom, 4 feet deep, and 5 feet wide at the top, but lateral pressure in the wet soil soon narrowed the top width to about 3 feet. The soil was so peaty that the slopes have stood up well. In one ditch that has not been

filled up, the spade marks ten years old are still visible on the slopes. Nevertheless, the sides undermined and broke off in places. Particles of floating peat lodged against weeds, straws, or sticks that found their way into ditches, so that the ditches had to be cleaned out about once a month. All of these ditches, aggregating 880 rods, were connected with the reservoir from which the water was pumped into the lake.

It was hoped that these ditches would permit the soil to settle and become firm and dry, so that the wild marsh grass could be harvested where the cat-tails and willow brush were not too thick. The wire grass, and in places the blue joint, grew luxuriantly but the ground was too soft and wet for horses. They mired within 10 feet of the empty ditches even when wearing bog shoes. The more valuable grass was cut with a scythe and carried off on poles. The rest was not cut at all.

Wind and Gasoline Failed

A geared windmill was erected to run a bucket water elevator. A 16-inch reverse-turbine pump was installed to supplement the

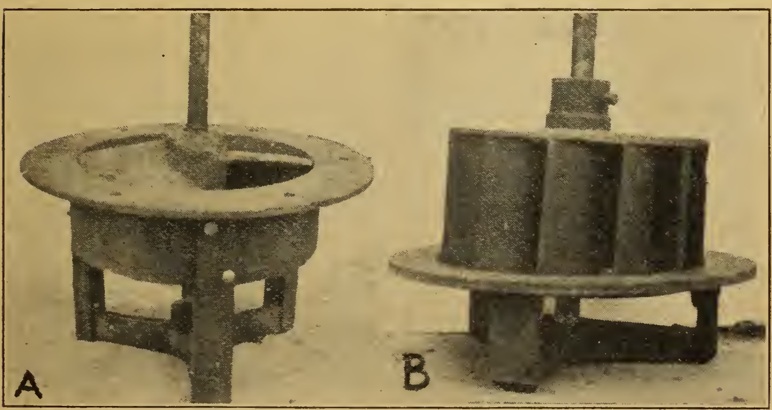


FIG. 3.—A. THE AUGER PUMP

Its big advantage is that sticks or other debris do not clog it. Its efficiency is about 40 per cent with 600 revolutions per minute lifting 2780 gallons per minute 5 feet high and requiring a 9 to 13 h. p. motor. Lower speed gives less efficiency.

B. THE REVERSE TURBINE-PUMP

An efficiency of 40 per cent has been recorded with 400 revolutions a minute, lifting 2780 gallons per minute 5 feet high and requiring an 8 to 10 h. p. motor.

elevator. This was run by a 12 h. p. gasoline engine. In 1910 the lift was about 5 feet. It was soon evident that the amount of water lifted by the windmill and elevator was small in comparison to that which had to be pumped and the wind power was abandoned after a trial of about two months. An attendant started the gasoline engine and turbine pump and emptied the ditches regu-

FIG. 4.—THE PUMP HOUSE

The foundation had to be heavily reinforced because of the soft footing. The crack in the wall is due to pouring the concrete at different times.

larly three times a day, the last being at 5 o'clock. By the next morning the water in the ditches would be within a few inches of the top. The pump would empty the ditches, aggregating 880 rods in about an hour, ordinarily. During rainy weather the pump was started more frequently or was run for two hours or more at a time.

It soon became evident that the soil could not be made dry enough so long as the ditches were allowed to fill up with water during the night. It was too expensive to dig a reservoir any larger than 10 feet by 50 feet and this did not have enough storage capacity to last all night.

Electric Power and Deep Tile Succeeded

The efficiency of frequent pumping and tiling was tested in 1914. With the aid of two students the gasoline engine and pump was started every three hours or oftener during the night; and a farm hand did the same during the day. The experiment began April 20, 1914, and continued for twenty days.

The students had previously laid two lines of 4-inch tile 300 feet long and 2 rods apart, one line being 1 rod from an open ditch. The gradient was .1 for each 100 feet. They were 3.0 feet deep at the outlet and about 2.5 at the head. The shallowness of the reservoir did not permit greater depth.

On May 8 the tiled plot was plowed with horses. This was the first plowing that had ever been possible on the lake-level marsh. A small portion at the upper end of the lines of tile where the water table in the observation holes came within 2 feet of the surface of the ground was too wet even then to hold up the horses.

The experiment proved that if the tile could be laid deep enough and if the pumping were done at such frequent intervals that the tile outlets did not become submerged, the lake-level marsh could be drained and plowed. The proposition seemed sufficiently feasible to warrant the installation of electric power which lends itself admirably to automatic control. A 10 h. p. electric motor was installed. A float on the water in the reservoir connected with a switch started the pump just before the tile became submerged

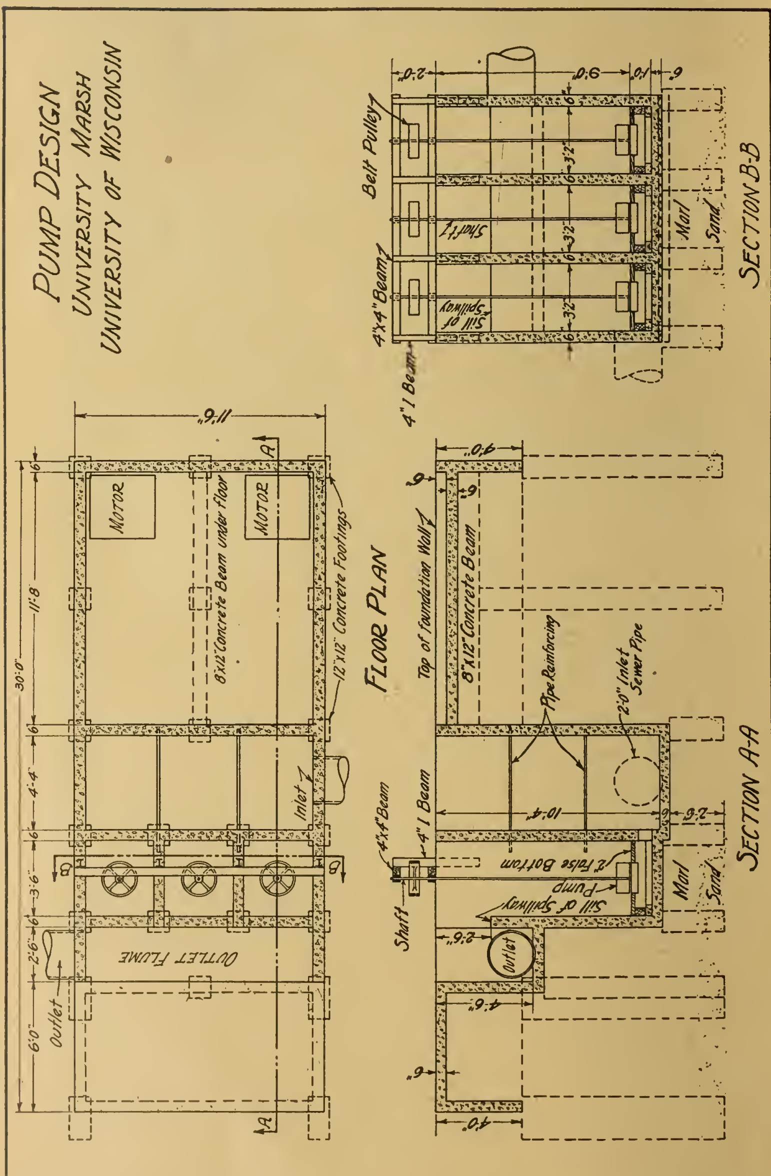


FIG. 5.—PLANNED FOR EMERGENCIES

There are three pump chambers with pumps installed in two of them, one for steady use and the others for emergencies. The foundation is deep enough to take care of future settling of the marsh.

and stopped it when the reservoir was empty. The reservoir was deepened a trifle and more tile were laid in 1914. From 7 to 15 acres has been tiled every year since that time.

For several years plots 16 rods wide had ditches on three sides of them in which the water was kept 3½ feet below the surface by pumping day and night. Yet they never became dry enough even during a summer drouth to permit the marsh grass to be mowed with horses. It was not until lines of tile 4 rods apart and about 4 feet deep were laid that satisfactory drainage resulted. Where the depth of the reservoir and pump limited the depth of the tile to 3 feet, the lines had to be 2 rods apart to permit plowing. Furthermore, the peat above the tile has shrunk with drainage and decomposition. Tile that formerly had 4 feet of peat over them now have only about 3 feet, and those that had 3 feet now have but little more than 2 feet. In 1919 the shallower reservoir was deepened again and these shallow lines are now being dug up and relaid at a greater depth—in some places 5 feet deep.

The Soils Department in 1919 and 1920 ran a series of tests on a portion of the marsh that was tiled in 1918. These tests show that the yield of corn can be raised from 34.5 to 83.5 bushels to the acre by proper fertilization.

A 24-inch breaking plow drawn by a tractor was found to be the best method of breaking the marsh. Thereafter a disc plow did better work than a mold-board plow because the latter would not scour due to the looseness of the soil.

Corn has proven to be the most satisfactory crop on the drained peat. Even the first year after drainage, good crops of corn result. This is fortunate because the University Farm requires a large area of corn within hauling distance to fill its silos. Timothy and alsike has proven to be a good crop where the tile were unable to cope completely with excessive seepage.

DETAILS OF THE DRAINAGE SYSTEM

About 15 acres of the west end of the marsh was higher than the rest, it being from 4 to 7 feet above the normal lake level. It was a "springy" marsh kept wet by the seepage from

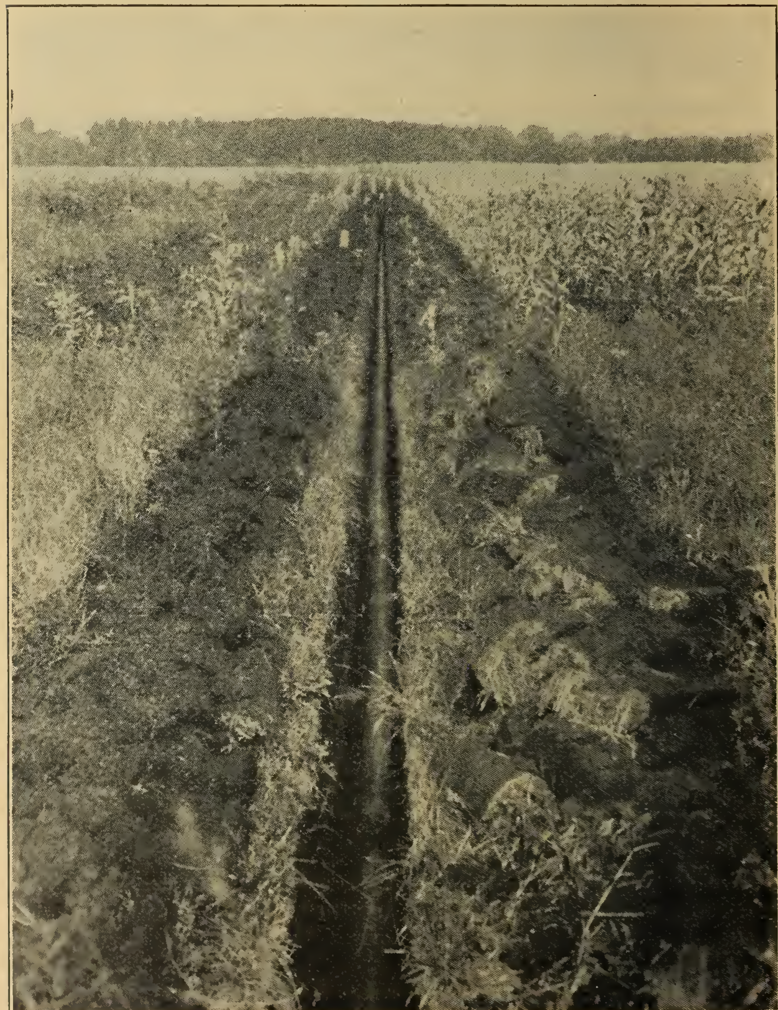


FIG. 6.—REPAIRING THE SYSTEM

The original tile drainage system had lines 4 rods apart. In some places it was necessary to put in lines later midway between the original lines. In other places where the lines were deeper and seepage was less, satisfactory drainage has resulted with lines 8 rods apart.

the upland. The parallel laterals of Group 1 were put in 4 rods apart to discharge into Main A. (See Fig. 11.) The laterals had a gradient of .1 in 100 and the main .05 in 100. While the laterals could not be put as deep as desired, they cut off the seepage fairly well. They collected enough water to fill the main at the outlet of Line 1, but little or none of the water reached the outlet. It leaked back into the soil along the main and entered the lower marsh from which it had to be pumped, thus defeating the original purpose which was to carry this seepage to the lake without pumping. Main A was dug up in 1915 and relocated to carry the water directly to the pump.

FIG. 7.—CORN POOR BETWEEN LINES OF TILE

Taken near the head of Lines 8 and 9 Group VIII before Line 29 was put in for relief.

The history of Main A taught two lessons: (1) A line of tile to cut off seepage effectively must have a liberal fall; and (2) when water is carried in a tile through a soil that would be otherwise dry, the roots of willow trees will enter the tile. To obtain enough soil to cover the tile properly it was located on land reasonably dry and about 4 feet higher than the lake. A willow tree had sent one root through a crack between two tile. This root sent out myriads of fibrous branches which after five years completely filled the 8-inch tile for about 15 feet above the point of entrance. This was not the direct cause of the failure of this

main, however. The heavy leakage from this main back into the marsh was observed the first year after it was laid, or before the roots had had time to fill the tile.

The land drained by Group XI was the most difficult to drain. The soil was muck one foot deep lying on about three feet of

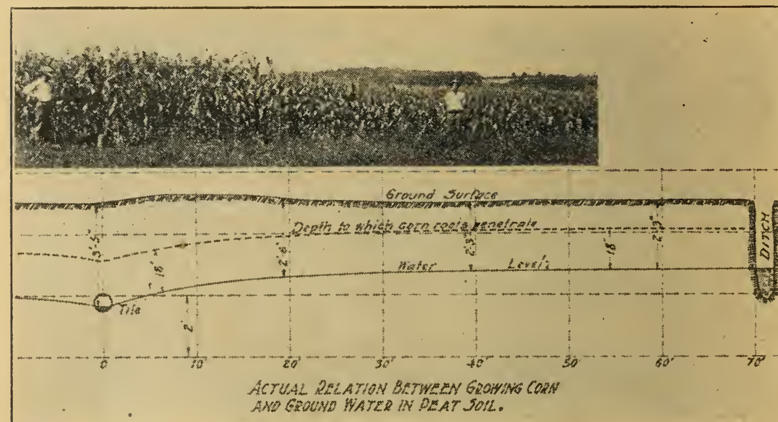


FIG. 8.—THE CORN SHORTENS AS THE WATER TABLE RISES

Taken between Line 1 Group VIII and the ditch at the side of Willow Drive.

clay under which there was water-bearing sand. To dry up the springs that broke through the clay, lines had to be put as close together as 10 feet in some places. When the 8-inch main was laid in 1916 it was put 5 feet deep. It was difficult but very effecive to get this main down into the water-bearing sand. This so relieved the pressure that springs 4 rods away were dried up. Another effective device was a column of the vertical tile reaching from the bottom of the horizontal tile through the clay into the sand. This permitted the water to rise easily into the tile and escape, thus relieving the pressure that caused the springs.

It has been difficult to get protection at all times from the ditch and dike on the north and west side of the marsh. Sediment is deposited in it from the steep hillsides and it has to be cleaned with teams and scrapers once in two years. The ditch and dike are seeded to timothy, but when the grass is tall the flow during floods (it is dry the rest of the time) is retarded and some of the

water overflows the dike. This dike has been more successful, however, than Cinder Drive, on the south side of which a ditch was originally dug to carry the flood water to the lake by gravity. This ditch was so nearly level that even in a small flood more water flowed over the drive near the outlet of Line 101 than flowed east into the lake. In 1916 another drive about half way up the hill on the south side of the marsh was raised so that it catches the surface water; and a ditch on its upper side carries

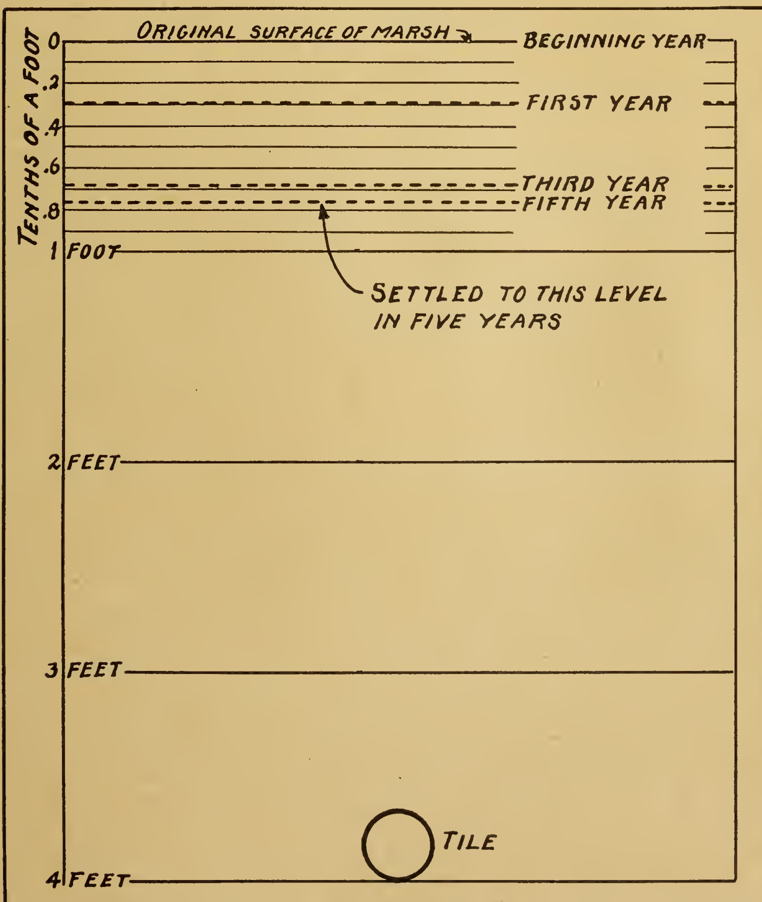


FIG. 9.—HOW THE PEAT SETTLED

The tile were originally between 3 and 4 feet below the surface of the peat. The shrinkage is confined almost wholly to the peat laying above the tile.

this water to a creek entering the lake. Line 117 has carried seepage better since it has been tapped by Line 103.

A glance at the map shows that in general the laterals of 4 or 5 inch tile are 4 rods apart, except where excessive seepage or limited depth made it necessary to put the lines 2 rods apart or closer. Generally the laterals do not exceed 40 rods in length. The mains are numerous and large enough to compensate for the limited gradient of .05 in 100, which puts them deep enough to afford the laterals a gradient of .1 or .2 in 100 and a depth of about 4 feet.

Measurements in 1914 showed that the third ditch from the lake carried more water than the first one. It appeared that the third ditch was receiving seepage both from the lake and from the upland. By 1920 it was evident that the line of tile nearest the lake carried more water than any other lateral on the marsh, and that the seepage from the lake was increasing. The Willow Drive, the turnpike diking off the lake, is merely built up about 2 feet above the surface of the marsh and nothing has ever been done to strengthen its foundation so as to stop seepage. Muskrats have burrowed beneath this drive and repeatedly these holes have had to be plugged.

SURFACE, SOIL AND TILE EXAMINED

In the fall of 1919 the Agricultural Engineering Department undertook an investigation of the conditions then obtaining on the marsh for the purpose, if possible, of securing reliable fundamental information which might be of value in carrying out other reclamation work throughout the state. The investigation included a compilation into one system of all the notes and data on previous experimental work and a comparison drawn between original and recent conditions, particularly as to the shrinkage of the soil volume. The map (Figure 11) and Table 1 give the results in detail.

TABLE I.—SETTLING OF TILE AND SURFACE. ELEVATIONS IN 1920

Lines	Date of laying	Number of stations	Average surf. elev. when laid	Average depth when laid	Surface settle-ment	Tile settle-ment
I—0 to 6	1910	64	854.5	3.07	.406	.107
V—6 to 9	1919	15	848.8	3.79	----	----
V—10 to 12	1919	9	849.4	3.51	----	----
V—13 to 19	1918	21	848.8	3.71	.298	.189
V—20 to 23	1916	25	848.7	3.76	.680	.081
V—23 to 32	1916	33	849.8	3.83	.591	.008
VII—1 to 7	1914	27	848.7	3.35	.760	.037
VIII—6a	1914	2	849.0	3.16	.805	.215
VIII—7 to 16	1916	47	850.1	3.77	.660	.054

Lines	Remarks
I- 0 to 6	Peat or muck to 1.5; clay to 4.5; sand beneath
V 6 to 9	Peat 4 to 6 feet. Settlement not measured
V-10 to 12	Peat 4 to 6 feet. Settlement not measured
V-13 to 19	Peat 4 to 6 feet. One Station Line 6 excluded
V-20 to 23	Peat 4 to 6 feet. Seven stations of Line 23
V-23 to 32	Peat 2 to 4 feet. Five stations of Line 23
VII- 1 to 7	Peat 4 to 6 feet. Near pump house
VIII-6a	Peat 4 to 6 feet. Near pump house
VIII- 7 to 16	Peat 4 to 6 feet. Receives upland seepage. Two stations Line 10, one station Line 11, and one station Line 15 excluded.

Settlement of surface levels showed that the surface of Plot S (surface drained for six years but not tiled) had settled .4 feet below the marsh on the lake side of the drive that serves as a dike. While Plot S was too wet to plow, it did get enough drainage to change the character of its wild vegetation. The land tiled in 1914 had settled about .75 feet by 1920. Practically all of the shrinkage had taken place in the peat above the tile, and settling of the tile themselves was comparatively small. A comparison of the levels taken on the marsh surface in 1910 and 1914 when the automatically controlled pump was installed showed that there was practically no settlement during those four years of intermittent drainage.

The settlement varied with the seepage. Group V Lines 20 to 23 laid in 1916, underlaid by marl and water-bearing sand, and receiving much seepage showed more surface settlement than Group V Lines 24 to 32 laid in 1916, where the subsoil was clay and the seepage was less. The peat lying on the water-bearing sand was buoyed up by the pressure from below and the settlement was great when that pressure was relieved by drainage. Group VIII, Lines 4, 5, 6, 19 and 20, overlying submerged tongues of sand causing great seepage both from the lake and the hills,

showed the remarkable surface settlement of nearly one foot in two years.

Examination of Tile.—Complete levels were run through the body of the marsh both on the surface of the ground and on the tile, using the same stationing as was used in laying out the original work. For the purpose of getting the grade of the tile, a steel rod of known length was thrust down onto the tile, care being taken that the rod rested on the top of the convex surface. Lines of tile were opened for the purpose of examining their condition. This was done for the most part in groups, a group consisting of tile of the same kind and laid under similar conditions. If two or three pits in a group showed no evidence of unusual conditions, the group was assumed to be uniform, but if any unusual conditions were exposed further openings were made in sufficient number to ascertain the facts and, if possible, their cause.

Settlement of Tile.—Only two groups of tile were found to be materially below grade. Group VIII Lines 4 to 20 averaged .25 feet in settlement of tile. In this group the greatest variation was shown by the levels to be on the outer ends of the lines where the marsh was narrow and subject to the most seepage. The last two stations of VIII Line 6 sank an average of .53 feet while the surface above sank 1.05 feet. Group VIII Line 19 sank .35 feet and the surface .95 feet. The uniformity of settlement in the outer ends of all the lines shows that the discrepancy was not due to any error in laying the tile or in the levels, but to a general subsidence when the water was drawn off.

Group V Lines 13 to 19 were laid by a careless contractor who got his ditches too deep in places. To remedy this defect the lower grade was carried through to the outlet. This alteration does not appear in the notes and the tile grades were thrown out.

Rate of Settlement on Marsh Surface.—The time over which the records extend is not sufficient to establish an absolute rate of settlement of the marsh surface, but there are sufficient data on which to base an estimate. This seems to be very close to .25 feet a year for the first two years. After this the

rate drops off rapidly until at five years the total settlement has reached .76 and the rate of settlement about .04 feet (½ inch) a year but slowly decreasing. (The accompanying diagram Fig. 9 shows this more fully.) The settling for one year is the average of 21, for two years 44, for three years 105, and for five years 27 observations, the average depth of the tile when laid being about 3.7 feet.

FIG. 10.—THIS TILE WAS ABUSED

A clay tile lying on the surface of the ground throughout the winter freezes and thaws suddenly a great many times. This splits the walls and the tile are damaged more in a single winter than they would be in 100 years if covered with 2 feet or more of earth.

Decrease in Weight with Decay.—In order to ascertain what became of the material which shrank away upon drainage, pits were dug—one in the cultivated portion (middle of Group VII), and the other in the untiled marsh (Plot S)—in order that the original conditions should be as nearly alike as possible. From these pits, samples were taken at intervals of a foot. Before the samples had time to dry they were cut into 6-inch cubes and carefully weighed. They were then dried to constant weight at 110°C and again weighed. The results are shown in Table II. The difference between the weights of the bottom samples is most remarkable and probably represents the mineral matter brought into the peat by ascending seepage waters. The last foot of the untiled soil was entirely

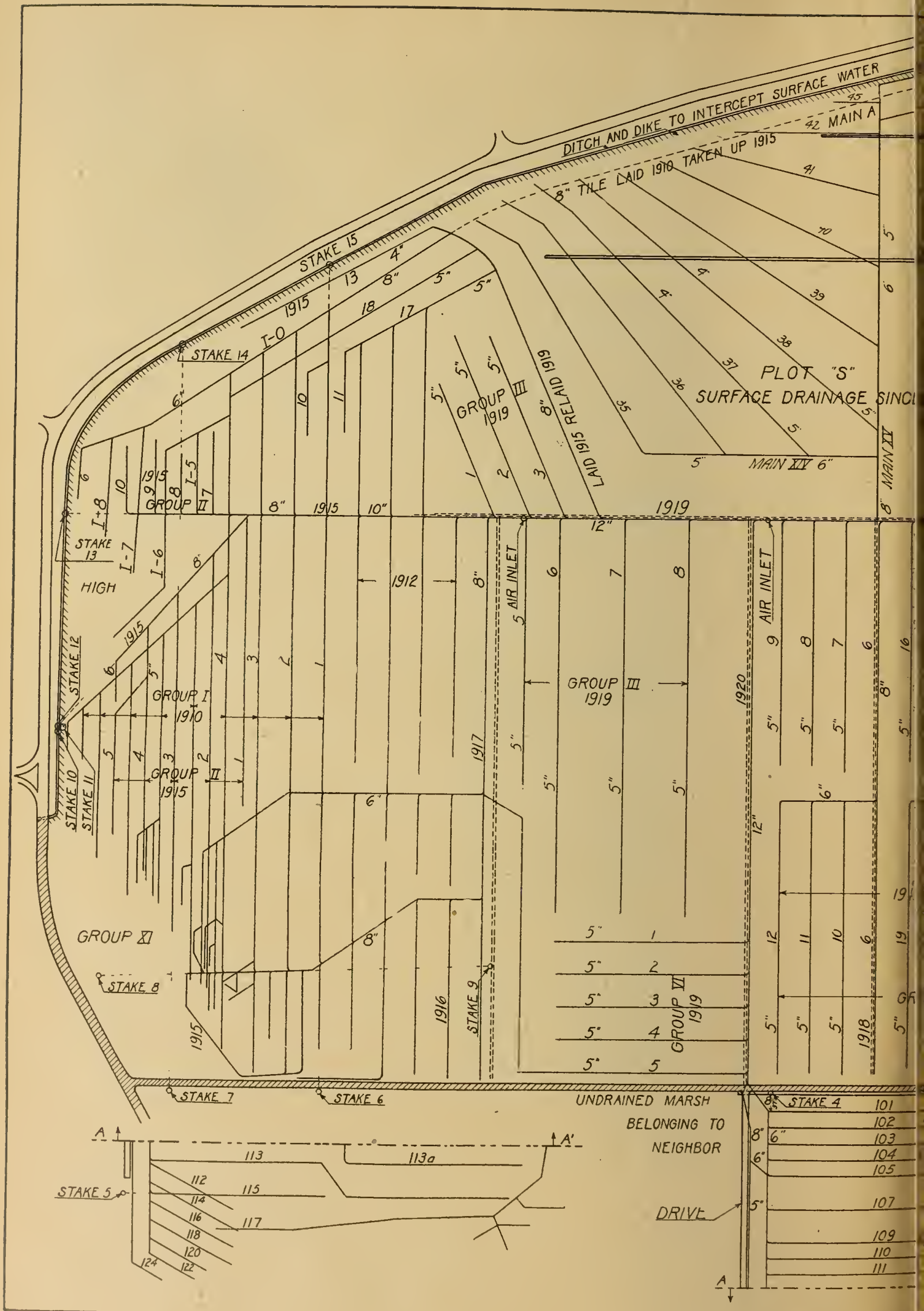
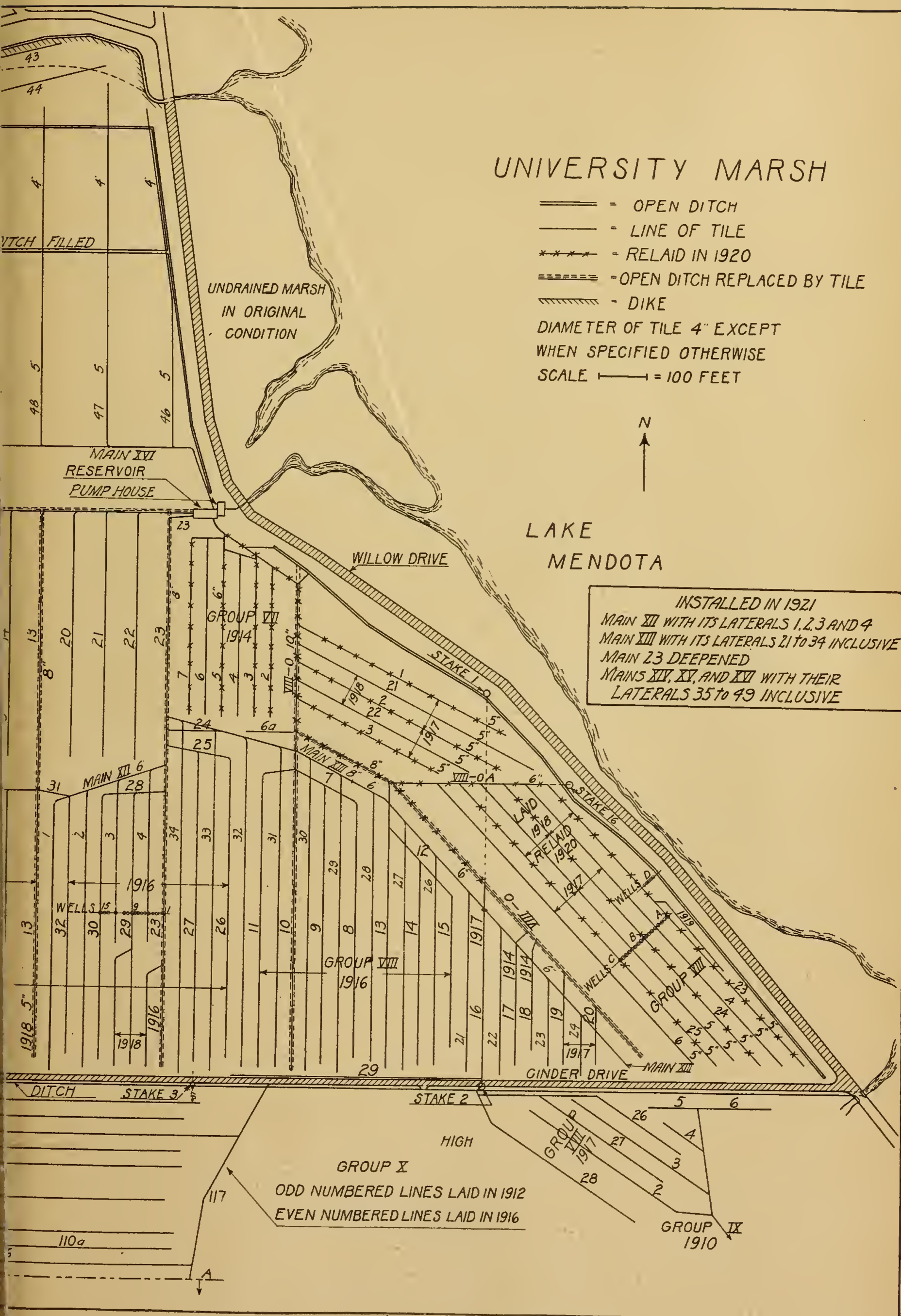


FIG. 11—MA

Note the reference stakes (iron pipes) that have been driven in convenient plac



MARSH

help locate the principal lines of tiles. Others can be located from these.

TABLE II.—WEIGHT OF WET AND DRY PEAT

Section measured	Tiled and cultivated six years				Untiled and uncultivated			
	Elevation in feet	Actual weight in lbs. per cubic foot		Calculated weight of section in pounds	Elevation in feet	Actual weight in lbs. per cubic foot		Calculated weight of section in pounds
		Wet	Dry			Wet	Dry	
Top 4 ins.	847.94 to 847.63	23.34	8.28	2.76	848.3 to 847.97	13.73	6.46	2.19
4 to 6 ins.	47.63 to 47.44	-----	-----	1.40	47.97 to 47.81	-----	-----	1.41
6 to 12 ins.	47.44 to 46.94	61.06	12.49	6.25	47.81 to 47.31	64.27	10.48	5.24
12 to 18 ins.	46.94 to 46.44	-----	-----	6.59	47.31 to 46.81	-----	-----	5.65
18 to 24 ins.	46.44 to 45.94	66.61	13.88	6.94	46.81 to 46.31	64.57	12.57	6.28
24 to 30 ins.	45.94 to 45.44	-----	-----	6.85	46.31 to 45.81	-----	-----	6.30
30 to 36 ins.	45.44 to 44.94	65.45	13.51	6.75	45.81 to 45.31	65.83	12.62	6.31
36 to 42 ins.	44.94 to 44.44	-----	-----	7.29	45.31 to 44.81	-----	-----	6.28
42 to 48 ins.	44.44 to 43.94	66.63	15.65	7.82	44.81 to 44.31	64.81	12.50	6.25
48 to 54 ins.	43.94 to 43.44	-----	-----	7.83	---------------	-----	-----	-----
54 ins.	---------------	Marl	-----	-----	---------------	-----	-----	-----
48 to 58½ ins.	---------------	-----	-----	-----	44.31 to 43.44	64.89	8.87	9.34
70 ins.	---------------	-----	-----	-----	---------------	Marl	-----	-----
Weight of column above elevation 843.44				60.48 lbs.				55.25 lbs.

different in character from any other sample taken out. It was extremely soft and light buff in color, darkening to almost black within five minutes after exposure to the air. The column of tiled soil one foot square and extending from elevation 843.44 to the surface, seems to have retained its original weight fairly well even though it has lost in volume. The weight of each cubic foot or portion thereof was calculated from the

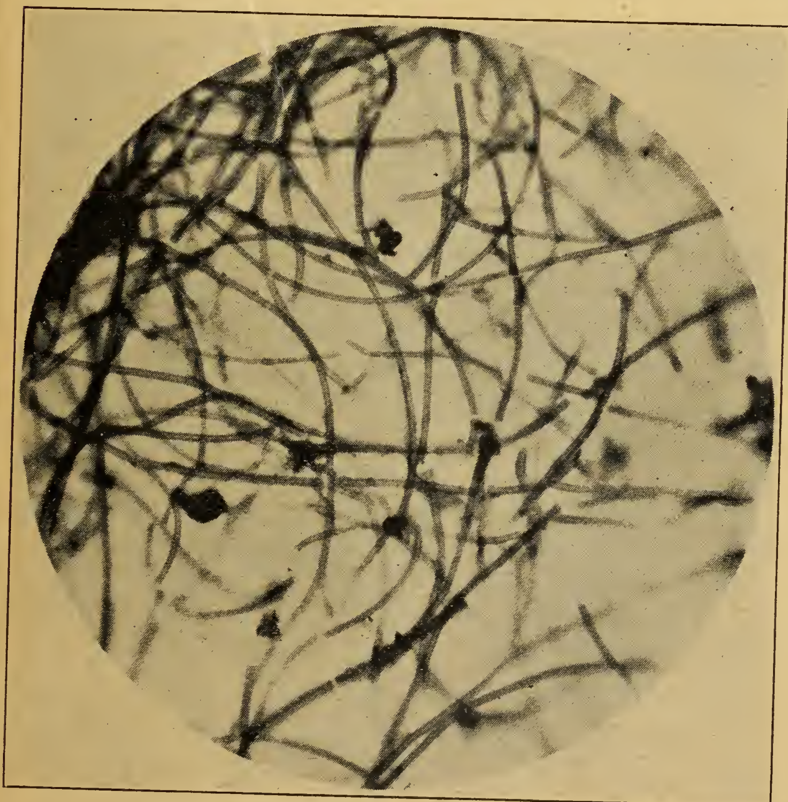


FIG. 12.—IRON BACTERIA THAT CLOG TILE

Leptothrix ochracea, from University Marsh. Colored with gentian violet. Magnified 650 times. The black masses are ferric hydroxide. In the tile they cause an accumulation of yellow slime.

actual weight of the 6-inch cube typical of it—except the surface 4 inches which was weighed separately.

Frost Action on Tile.—Four of the lines of tile laid in 1910 crossed the entire width of the marsh. Near the upper or

southerly end the land dropped into a hollow or swale in which the clay was covered by about one foot of black muck. In order that the tile should not be too deep for the greater part of the distance the tile were necessarily shallow in passing through the low ground. In the interval since the tile were laid the black muck had entirely rotted away and disappeared leaving the tile less than a foot deep. Here they were exposed to repeated freezing and thawing and probably had been for years. The tile were of good clay and well burned. No trace of any failure or disintegration showed. At the outlet of the easterly main, where it enters the pump house reservoir, six feet of the 12-inch clay tile exposed to direct frost action scaled off and collapsed in two winters.

Even with a light covering the freezing takes place slowly; the entire wall of the tile is the same temperature and formation of ice crystals goes on uniformly. Any excess moisture which may develop, due to expansion of the freezing water, is permitted to escape through the partially frozen walls and no rupture takes place. Such ruptures do occur at an exposed outlet subject to sudden freezing. This is well illustrated by Figure 10. This was a 3-inch clay tile which was for ten years in an underdrain, then taken up in perfect condition and replaced by larger tile. It then lay on the ground for five winters with the result as shown. The upper surface is more than half scaled away while the lower side which lay on the ground and was protected from direct frost is still in nearly perfect condition.

Iron Bacteria.—While the work of examination of the marsh was going on an accident caused a stoppage of the pump. As the stoppage occurred during the night it was not noticed until the water had risen to within about two feet of the surface of the land. When the pump was started again a great volume of water had to be taken care of. As there was considerable "head" above the mains, the water flowed much more rapidly than at ordinary times. The easterly main, marked VIII-O on the map, brought into the reservoir small flocculent orange colored masses which floated in the water and slowly settled. These masses had evidently been torn from the walls of the

tile by the rush of water. Upon examination a similar growth was found in the ditch beside Willow Drive. A specimen was taken to Dr. E. B. Fred of the Agricultural Bacteriology Department who identified it as iron bacteria, chiefly *Leptothrix ochracea (chlamydothrix ochracea),* though several other forms were also present.

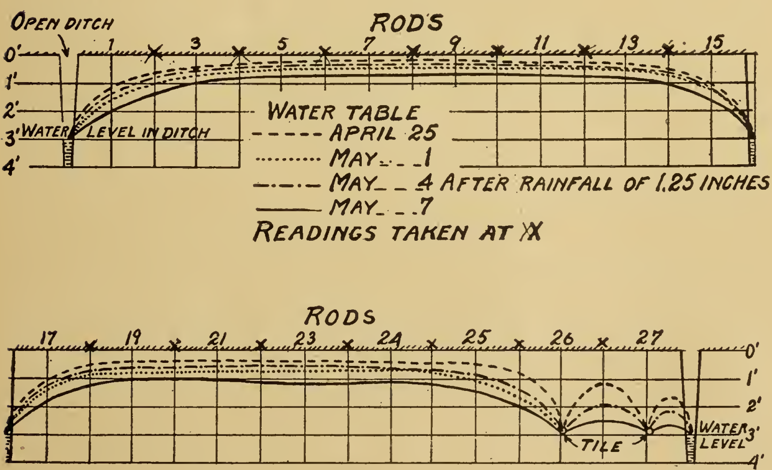


FIG. 13.—WATER TABLE TOO HIGH

Only near the open ditches or a line of tile is the water table where it should be—three feet below the surface.

As the growth of these organisms might have a very important bearing on the efficiency of the tile, the broken masses were traced to their point of growth. Two systems were found to be affected, both of them near the lake. Group VII, Lines 1, 2, 3, 4 and 5 were coated on the inside below the water line with masses that would average from ¼ to ¾ of an inch in thickness—principally along the sides. All these lines were of clay tile. Lines 6 and 7 of the same system containing cement tile showed no bacteria. Group VIII, Lines 1 to 6 containing clay tile were heavily infected with masses up to an inch in thickness. In Line 5 one mass was noticed 8 inches long and reaching up to the surface of the water (more

than half the size of the tile) which was slowly moving down, pushed by the water behind it. On the other hand, no tile which came into the main from the south was infected. Neither was the main into which all tile emptied in common. The boundary between the infected area and the uninfected was clearly defined. Cement tile are inimical to these bacteria. So also is seepage from the upland. The bacteria were abundant where the seepage from the lake flowed through clay tile.

Harder* has done exhaustive research work on deposition of iron by various forms of bacteria. Ehrenberg in 1836 first discovered that bacteria were active in the depositing of iron. Harder groups the iron bacteria into three general classes: (1) those which extract carbon dioxide from ferrous bicarbonate and precipitate iron hydroxide in their cell walls; (2) those which do not require ferrous bicarbonate for their life process but precipitate iron hydroxide if soluble iron salts are present; (3) those which attack organic salts using the organic portion as a food and so precipitating the iron. Leptothrix belongs to the second class. Nearly all are what is known as "higher bacteria"—slender filamentous forms made of single elongated cells joined end to end. Some are flattened and double back on themselves forming a double spiral. Others are cylindrical and double back on themselves in a double spiral. but the greater number are single threads. All of them have the peculiar power of precipitating hydroxide of iron which later becomes oxidized and forms hydrated sesquioxide of iron which becomes bog iron ore. Leptothrix is primarily a soil organism and can grow without the assistance of iron compounds. Its habitat is, however, in bogs where iron is present in considerable quantity, some of it in the form of organic salts.

During the winter (1919-1920) the masses of bacteria in the tile in the marsh became much smaller but persisted in the ditch beside Willow Drive. In fact they grew faster there, probably due to a higher lake level and more abundant water. The masses in the tile grew again in the spring but in the summer of 1920 the main into which the infected tile emptied was lowered

*E. C. Harder, "Iron Depositing Bacteria and Their Geologic Relations."

In the process the laterals were dammed and drained several times and the rush of water cleaned them out. A month after work was finished the bacterial masses had again grown to considerable size.

There may be many places where tile are laid in a constant flow of water, that these organisms will give considerable trouble. In localities where this occurs it seems best to lay the laterals so that they may have a short sharp run to the main or to lay out the system in a way to let each lateral catch some upland water. A temporary cure for iron bacteria would be a small application of copper sulphate. Care should be taken that the amount of the chemical used is not enough to kill fish in the stream or lake into which the drains empty. Trout die if copper sulphate is used stronger than .14 parts per million while it takes .2 and .3 parts per million to kill leptothrix. Pickerel, perch and black bass, however, in the order named, can endure copper sulphate in strengths ranging from .4 to 2.1 parts per million. By stopping a drain temporarily, a concentrated solution may be kept for a time in contact with the bacteria. Upon discharging this into a creek or lake, this solution becomes so diluted that even trout are safe.

PUMP AND POWER MEASUREMENTS

Records of the amount of electricity consumed were made from May 9 to June 9, 1916, and again from October 24 to November 25, 1920. A tested meter was obtained from the Department of Electrical Engineering. In the 1916 test, 1760 kilowatt hours were consumed in 31 days; and in 1920, 1830 kilowatt hours were consumed in 32 days. In each case it averaged about 57 kilowatt hours a day for the whole period. The area drained is about 130 acres. At 2 cents a kilowatt hour the cost of power is approximately a cent an acre a day. During the 1920 test the rainfall amounted to 1.75 inches which fell as follows: October 26—.06; November 1—.68; November 6—.57; November 8—.15; and November 21—.27. From November 5 to 15 the power consumed averaged 92 kilowatt hours a day, but from November 15 to 18 it averaged

only 23 kilowatt hours a day. In 1916 there were several 5 day periods when the power consumption was less than 40 kilowatt hours a day.

Dry Weather Seepage—On October 24, 1920, a detailed study of the operation of the pump was made from 6 a. m. to 6 p. m. On that day dry weather prevailed, so that the pumping represented the seepage, ten days after a rain of any consequence.

The pump is a 16-inch auger having a two-bladed impeller, each blade making 4 inches more than one-half of the circumference in length and having a 4½ inch lift in one-half revolution or 9 inches in a whole revolution. The drive pulley is 16 inches. The motor is a 3 phase, a. c. 10 h. p. and has an 8-inch drive pulley. The shafts are set about 12 feet apart, and there is a quarter turn in the belt from the horizontal motor to the vertical pump shaft. The motor has ample power to drive the pump and the speed remained constant at 600 r.p.m.

The water was measured as it ran away from the pump over a 34-inch weir. It required 13 seconds after the starting of the pump before the water flowed over the weir, which it did with a rush. At the end of each run the pump continued to operate and the water to flow over the weir for a period of 4 seconds after the throwing out of the switch. As the water over the weir died down from full flow to nothing, it was assumed that the actual flow was equal to the average flow for half the time or 2 seconds. The effective run of the pump was therefore 11 seconds less than the actual time between the opening and the closing of the switch.

The pump started and stopped 39 times in 12 hours. It ran a total of 6,252 seconds. Subtracting 11 seconds for each of the 39 runs leaves 5,823 seconds of effective pumping or about 2½ minutes at a run. The average head over the 34-inch weir was .55 feet. For 5,823 seconds this gives a discharge of 22,457 cubic feet for the 12 hours. The current consumed was 10 kilowatt hours in the 12 hours or 20 kilowatt hours per day.

The elevations ascertained were as follows:

Level of lake (feet above sea level)....................848.92
Level of weir (feet above sea level)....................849.34
Top of water when pumping (feet above sea level)....................849.89
Height of water at start of pump (feet above sea level)....................843.43
Height of water at stop of pump (feet above sea level)....................841.93
Height of water at end of back lash (feet above sea level)....................842.70
Height of water over weir (feet).................... .55
Head over pump at start (feet).................... 6.46
Head over pump at stop (feet).................... 7.96
Average lift for the day (feet).................... 7.21

Every time the pump stopped, 85.8 cubic feet of water ran back through the pump into the reservoir. In 39 runs this amounted to 3,346 cubic feet which was wasted. It amounted to 15 per cent of the water that went over the weir. Since this water was lifted to a height averaging only one-half that of the water that went over the weir, the waste of energy is only 7½ per cent. During periods of heavy pumping when the run of the pump is 6 or 7 minutes, the percentage of waste is less than that.

The total effective inlet of the pump is its cross-sectional area of the pump minus the area of its hub or $(0.67^2 \times 3.1416)-(0.16^2 \times 3.1416)=1.33$ sq. ft. The lift being 9 inches and the speed 10 revolutions per second, the volume described by each revolution of the pump is $1.33 \times .75 \times 10=9.97$ cu. ft. per second, as compared with an actual discharge of 3.85 cubic feet per second. It would seem that the speed of the pump might be considerably reduced without cutting down its efficiency.

TABLE III.—SOURCE OF SEEPAGE

System	Acres drained	Cu. ft. discharge in 12 hrs.	Discharge per acre per day	Inches from area in 24 hrs.	Remarks
15-in. main	80	2,430	60.75	.0156	Underlaid by clay
8-in. main	13	10,627	1,634.92	.45	Main and laterals deep in sand
Balance of tract	37	9,400	509.46	.14	Includes reservoir at pump house and 20 acres not tiled

Areas Supplying Seepage Water.—In order to ascertain where this water was coming from, a 9-inch weir was put in at the mouth of the 15-inch main and an 8-inch weir on Main VIII, 20 feet below the triple junction at Station 7+49. The measurements are shown in Table III. The average acre near the lake had about 27 times as much seepage as the average acre in the 80-acre tract drained by the 15-inch main. Near the lake the seepage amounted to .45 inches a day while farther away it was only .0156 inches.

TABLE IV.—DAILY AMOUNT OF WATER PUMPED IN SECOND-FEET AND ACRE-INCHES

Date	Period pumped in minutes	Rainfall inches	Average lift	Water pumped	
				Rate second-feet	Acre-inches per day
1914					
April 20	448	----	1.78	14.1	105.2
21	940	----	3.42	4.6	68.7
22	575	----	3.74	3.21	31.0
23	735	0.03	4.46	1.2	14.7
24	505	0.87	4.50	1.82	9.22
25	320	----	4.51	2.47	13.2
26	155	----	4.17	1.44	3.7
27	130	0.23	4.63	1.44	3.14
28	325	0.36	4.51	1.59	8.6
29	210	0.05	4.58	1.96	6.85
30	180	0.01	4.37	2.47	7.41
May 1	135	----	4.72	1.34	3.02
2	205	----	4.32	1.80	6.14
3	305	1.26	4.05	2.16	10.8
4	370	----	4.18	2.47	15.2
5	360	----	4.54	3.36	20.16
6	510	----	4.61	2.47	21.0
7	225	0.05	4.59	3.36	12.6
8	350	----	4.71	1.82	10.62
Totals	6,783 minutes	2.86 inches	----	----	371.5 acre-inches

Measurements in 1914.—Table IV shows the amount of water that was lifted about 5 feet by a 16-inch reverse-turbine pump driven by a 12 h. p. gasoline engine in 1914. At that time about 20 acres of the higher marsh were tiled but only ¼ acre of the lake-level marsh was tiled. The rest of it was drained by 880 rods of open ditches 4 feet deep. The pumping amounted to 20 acre inches a day or about .16 inches from the entire area. In the 19 days this amounted to 3.04 inches as compared with a rainfall for that period of 2.86 inches.

The discharge of the pump was measured by a weir 5 feet wide. The head of the weir was read at intervals during the pumping period and averaged to compute the discharge. The lift was also recorded at intervals and averaged. The discharge of the pump was much greater for the low lifts, but the power required was also greater.

The height of the water in Lake Mendota varies as much as 3 feet. On June 1, 1919, it rose to 851.90, according to the city engineer of Madison. It has been as low as 848.5. At such low water periods the flash boards of the spillway of the pump are taken out to reduce the lift.

HEIGHT OF WATER TABLE

During the pumping test in 1914, observations were made upon the height of the water table at intervals of 1 rod between the open ditches and the two lines of tile that were laid. The results are shown in Figure 13. The rainfall during the period is shown in Table IV. At each observation pit, four

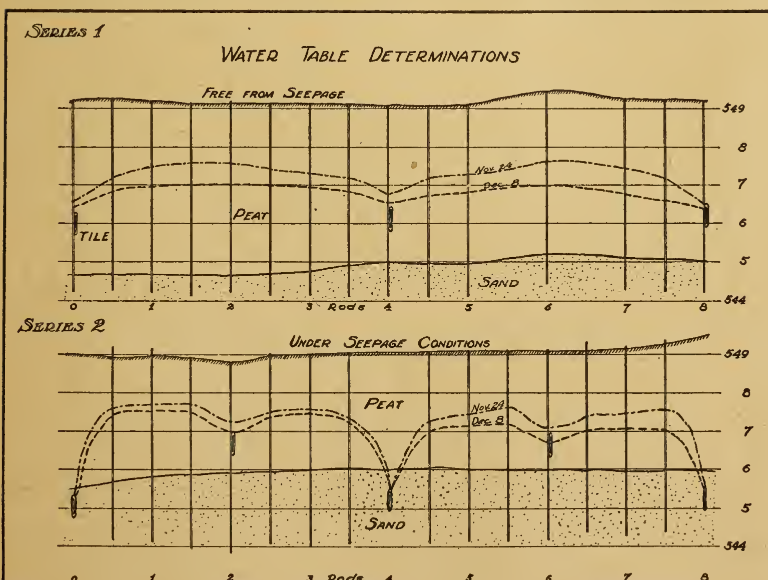


FIG. 14.—BETTER, BUT STILL TOO WET

In Series 2, the shallow tile belong to the original system. The deeper lines were installed later. Note how the deep, rather than the shallow tile, affect the water table.

5-inch tile were placed in a vertical column in a hole, the top of the upper tile reaching about to the surface of the ground and being used as a reference point in reading the height of the water in the hole. Even on May 7 when the water table was 1 foot below the surface, the land was too soft to hold up the horses.

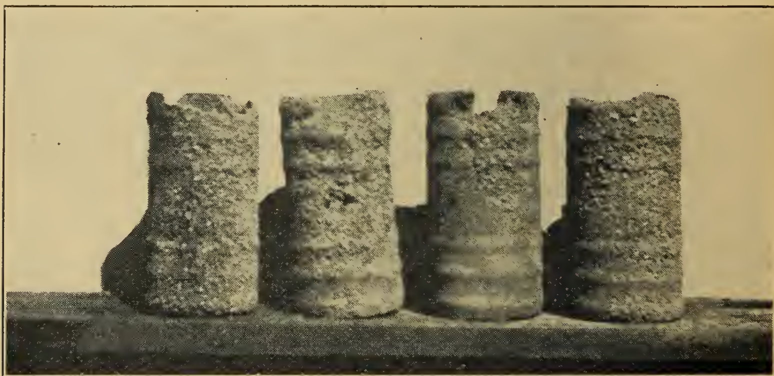


FIG. 15.—POOR CEMENT TILE FAIL

This tile was made too porous. It had been laid in a high lime muck for 4 years when this picture was taken.

Another set of observations began in November, 1920. In each hole five 5-inch tile were placed in a vertical column, the bottom of which reached to the sand in each case. Figure 14 shows the results to date. During this period the soil was dry and firm enough at the surface to hold up horses or tractors.

A peculiar feature of the observations now in progress is that the water table directly over a line of tile is in some places from 4 to 8 inches higher than the top of the tile, yet the tile were not more than half-full of water which ran swiftly in every case. This is probably due to the pressure of water from below and the slowness with which the water moves through the peat. It appears, however, that at Hole IX Series B where the tile are only 2 feet deep, the water table is as much above the tile as at Hole IX Series A where the tile are more than 3 feet deep. Even under these conditions the deep tile are the more efficient. At A, B and C the tile had just been deepened and the looseness of the peat over the tile accounts for the low water table there.

INVESTIGATIONS WITH CEMENT TILE

Several lots of cement tile were laid on the University Marsh. At the time they were purchased and laid they were thought to be the best cement tile available. Nevertheless, many of them were badly disintegrated or had totally collapsed at the end of six years. The action of the acids of the peat is the most probable cause of the distintegration. On the other hand, some good but not extra quality cement tile laid in the neutral peat on the University Marsh in October, 1919, had roughened but little by August, 1921, and were stronger than when laid.

Some cement tile manufacturers are now making an extra quality tile with walls so dense that the absorption of water is kept below 10 per cent after 5 hours of boiling. The following are the minimum wall thicknesses:

4-inch tile 5/8″ thick	8-inch tile 13/16″ thick
5-inch tile 11/16″ thick	10-inch tile 7/8″ thick
6-inch tile 3/4″ thick	12-inch tile 1″ thick

Decreased wall thicknesses may be compensated for by increasing the density, but it has not yet been proven that they will stand up in an acid peat, unless the peat is underlaid with clay in which the tile are imbedded. In such peat, and in most clays in Wisconsin, extra quality cement tile are satisfactory. For beds of acid peat underlaid by sand, or those so deep that the tile are not imbedded in the underlying clay, it is best for the present to give preference to good hard burned shale or clay tile even at the expense of high freight rates on such tile.

The findings on the University Marsh substantiated by similar findings in 20 cases in 10 counties in Wisconsin should be a solemn warning to the manufacturers of poor cement tile. The poorest cement tile have been made with small machines by farmers themselves. But little better than these are the cement tile made by the small plants not equipped with good workmen, good materials or a steam curing device.

DRAINED PEAT BURNS

In August 1919 during a dry period, a careless workman dropped a lighted match on the area drained by Group III. By the next morning about two acres had burned over, burning the peat to depths varying from 6 to 12 inches. The pump was stopped and the water from the lake was allowed to run back to put out the fire. Due to the buoyancy of the soil and the dense dry grass on the surface, it was difficult to immerse all parts of the burning marsh and it took two days to put out the fire. By that time about 4 acres had burned more or less. Usually the ashes from burned peat helps the next year's crop by making the potash more available, but for reasons as yet unexplained, the crop of corn on these four acres in 1920 was poorer than in the unburned area.

COST OF DRAINAGE

Open Ditches—Most of the ditching crew were student laborers.

The original ditches 1 foot wide at the bottom, 4 feet deep and 5 feet wide at the top were dug by hand. Men were paid $2.00 a day and the average cost of the ditches was 90 cents a rod, for the 880 rods. For about 100 rods the ditches reached through the peat and one foot into the underlying clay. This increased the cost. Where no willow roots bothered and the peat was 4 feet deep, the cost was only about 75 cents a rod. The peat was cut with hay knives or spades into blocks containing about 1 cubic foot and then heaved out with manure hooks.

While these ditches did not dry the land enough to prevent horses from miring, they did make the soil firmer. It would have been difficult or impossible to lay the tile subsequently had not these ditches been put in first as fore-runners. They made the soil firm enough so that the trenches stood up well while the tile were being laid, and even permitted the use of a caterpillar tiling machine, although the tile had to be carried 40 rods or more by hand, except on Plot S where a caterpillar tractor was used to draw light loads of tile on a wagon.

Protecting Ditch and Dike—Available roads were used as dikes.

The ditch and dike at the north side of the marsh was made about 2½ feet deep and 10 feet wide at the top. The earth excavated was used to make a dike about 2½ feet high in the lower side. The work was done with teams and scrapers during May 1910, when the ground was so wet that horses walked in the ditch with difficulty, sinking to their fetlocks in the soft clay. Here there was no peat at all on the surface and large boulders imbedded in the clay had to be blasted before they could be handled. The cost of this ditch was 55 cents a rod, figuring a team and driver worth 40 cents an hour, and a laborer 20 cents an hour.

The Pumping Plant—This includes no subsequent repairs.

The cost of the pumping plant including 2000 feet of transmission line, two 10 h.p. motors with transformers, and automatic devices; the pump house with two pumps completely installed, was about $2,200.

The Tile—This does not include surveying nor supervision.

The mains and sub-mains into which the laterals discharge aggregate 90 rods of 15-inch, 110 rods of 12-inch, 42 rods of 10-inch, 320 rods of 8-inch and 345 rods of 6-inch tile. The total cost of these was $3,100. The laterals are 8 rods apart on approximately 30 acres, 4 rods apart on 60 acres, and 2 rods apart on 40 acres, with about 1 acre that had to have lines 1 rod apart to dry up all of the persistent springs. These aggregate about 6,300 rods or nearly 20 miles and cost approximately $8,000. All but 5 carloads of tile were bought and laid at pre-war prices.

Cost Per Acre—The total cost of the drainage system may be itemized as follows:

Open ditches (later filled)	$790.00
Protecting ditches and dikes	170.00
Pumping plant	2,200.00
Tile mains	3,100.00
Tile laterals	8,000.00
Total	$14,260.00

This brings the average cost approximately $110 an acre for the 130 acres. The unusual seepage from the lake and through the underlying sand from the surrounding hills together with the pumping made the drainage of this marsh about 100 per cent more difficult than the average marsh land in Wisconsin. Nevertheless, it was profitable because of high land values adjacent to the University Farm.

CONCLUSIONS

1. The shrinkage of peat above the tile is such that tile may have to be relaid in from 10 to 20 years.
2. Tile 3 feet deep are too shallow. Tile 4 feet deep and 8 rods apart are more efficient than tile 3 feet deep and 4 rods apart. The most efficient tile in the deep peat or where seepage is great are those 5 feet deep acid peats.
3. Well-made cement tile are satisfactory in clay sub-soils and none but the best should be tolerated in any soil.
4. Peat disintegrates some cement tile. It has not yet been proven that even the best of cement tile will stand up in acid peats, unless imbedded in underlying clay.
5. The pump should be started before the tops of the tile outlets are submerged.
6. Where the reservoir is small the pump must be started at frequent intervals. An automatic starter takes the place of a constant attendant. Electricity lends itself to automatic control better than gasoline, steam or wind.
7. A simple auger pump that permits sticks and debris to pass through it without clogging or binding is most satisfactory.
8. An emergency pump for use in case of accident or unusual floods should be kept ready for action.
9. About ½ kilowatt-hour of power is the average used per acre in 24 hours to lift the water 7 feet. The minimum was ⅙ kilowatt hours per acre per day.
10. The dry weather seepage amounts to about .1 inch in 24 hours. The maximum requirement has been about .8 inches in 24 hours from the entire area.

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